Control ENGINEERING

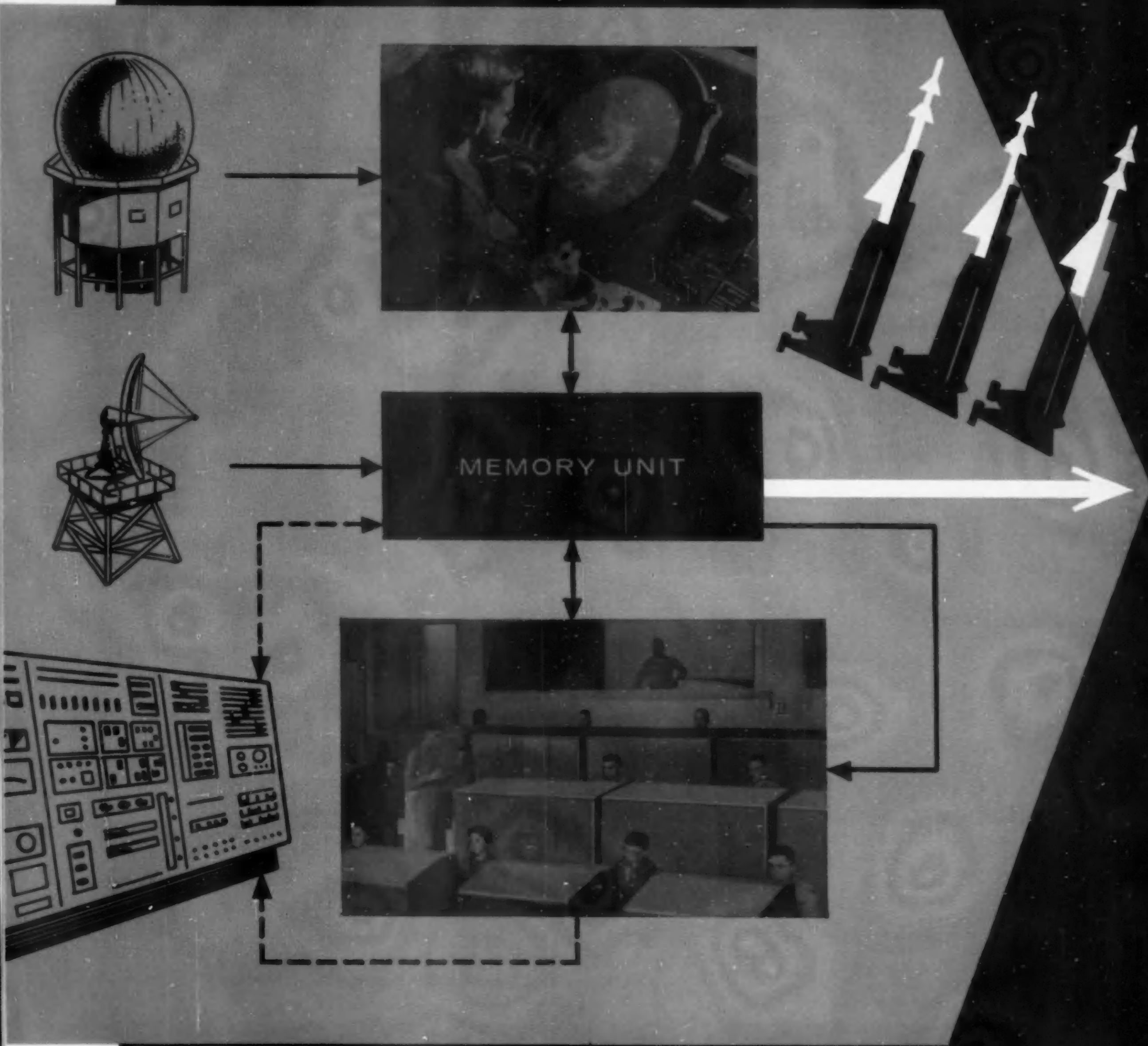
INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A McGRAW-HILL PUBLICATION

60 CENTS

OCTOBER 1958

What makes NIKE run? Missile Master!



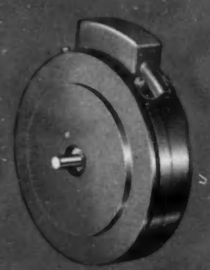
PARALLEL
UNAMBIGUOUS
STRAIGHT
BINARY OUTPUT

new!

capacity:
10 DIGITS.

resolution
per input
shaft revolution:
1024 COUNTS
(10 BINARY DIGITS)

accuracy:
1 COUNT IN TOTAL
CAPACITY.



10 BIT ENCODER

7, 13, 17, 19 DIGIT
CAPACITIES.

resolution
per input
shaft revolution:
128 COUNTS
(7 BINARY DIGITS).

accuracy:
ONE COUNT IN
TOTAL CAPACITY.
7 DIGITS—1 PART IN
128. 13 DIGITS—1
PART IN 8192. 17
DIGITS—1 PART IN
131,072. 19 DIGITS—
1 PART IN 524,288.

BINARY

capacity:
0-2000, 0-3600,
0-20,000, 0-36,000,
0-360,000 COUNTS.

resolution
per input
shaft revolution:
200 COUNTS.

accuracy:
1 COUNT IN TOTAL
CAPACITY.

BINARY
CODED DECIMAL

new!

MODEL: 758.
SINE AND COSINE
GENERATED
SIMULTANEOUSLY
IN STRAIGHT BINARY.

resolution
per input
shaft revolution:
9 AND 10 BITS PER
FUNCTION (7 AND 8
BITS PER QUADRANT)
WITH THE LIMIT 1;
ALSO QUADRANT
AND POLARITY
INFORMATION
PRESENTED FOR
EACH FUNCTION.

Shaft and Servo
driven hermetically
sealed units
available.

accuracy:
1 COUNT IN TOTAL
CAPACITY.

SINE COSINE

LIBRASCOPE

VERSATILITY IN DESIGN
FLEXIBILITY IN APPLICATION

packaged shaft-to-digital encoders

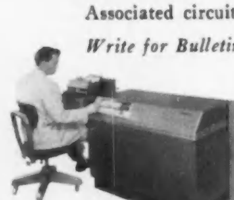
The Librascope Shaft Position-to-Digital Encoders are the most convenient and accurate devices for the conversion of analog shaft position into digital form. Added to the series of Librascope encoders, which include the Binary and Binary Coded Decimal, are the *new* 10-bit, 1024 count and Sine Cosine units. The 10-bit encoder provides parallel, unambiguous, straight binary representation of shaft position, and the Sine Cosine encoder is used where the natural functions of the sine and cosine are required with precision.

Features of Librascope encoders are: long life, high accuracy, double brush pickoff systems, serial and parallel readout into single or multiple scan matrices, solid state or vacuum tube, synchro-mounted, and time sharing (through the use of isolation diodes).

Associated circuitry can be designed to fit your data handling problem.

Write for Bulletins L10-1 and D-E10A for complete information.

Librascope's use of the LGP-30 computer simplifies complex design and production problems, and assures computer-engineered quality in meeting design and delivery schedules.



LIBRASCOPE

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CIRCLE 1 ON READER-SERVICE CARD

Your Design is better   Your Product performs better

with this full line of RAYTHEON DEPENDABLE DIODES RELIABLE RECTIFIERS

Germanium GLASS DIODES

TYPE	Working Voltage (max.) v	Forward Current at +1 volt mA	Reverse Current µA at v
1N55B	150	5	500 at −150
1N66A	60	5	50 at −10
1N67A	80	4	50 at −50
1N68A	100	3	625 at −100
1N95	60	10	800 at −50
1N126	60	5	50 at −10
1N127	100	3	25 at −10

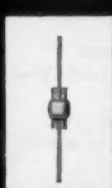
Type	Working Voltage (max.) v	Forward Current at +1 volt mA	Reverse Current µA at v
1N128	40	3	10 at −10
1N191	90	5	25 at −10
1N198	80	5†	75† at −10
1N294A	60	5	10 at −10
1N297A	80	3.5	100 at −50
1N298A	70	30*	250 at −40

*at +2 v   †at 75°C

Germanium VIDEO DETECTOR Diodes

for TV video and portable radio application;
low capacity video detection; efficiency controlled at 50 Mc

Silicon DIFFUSED JUNCTION GLASS RECTIFIERS



TYPE	Peak Operating Voltage −65°C to +150°C Volts	Ave. Rectified Current 25°C mA	150°C mA	Reverse Current (Max.) in µA at Specified Voltage Volts	25°C	100°C
1N645	225	400	150	225	0.2	15
1N646	300	400	150	300	0.2	15
1N647	400	400	150	400	0.2	20
1N648	500	400	150	500	0.2	20

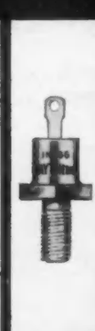
Silicon DIFFUSED JUNCTION RECTIFIERS

WIRE IN TYPES

TYPE	Peak Operating Voltage −65°C to +165°C Volts	Ave. Rectified Current 25°C mA	150°C mA	Reverse Current (Max.) at Specified PIV, 150°C mA
1N536	50	750	250	0.40
1N537	100	750	250	0.40
1N538	200	750	250	0.30
1N539	300	750	250	0.30
1N540	400	750	250	0.30
1N1095	500	750	250	0.30
1N547†	600	750	250	0.35

† Same as 1N1096   *to +135°C

STUD TYPES



TYPE	Peak Operating Voltage −65°C to +165°C Volts	Ave. Rectified Current 25°C Amps.	150°C Amps.	Reverse Current (Max.) at Specified PIV, 25°C µA
1N253	95*	3.0	1.0*	10
1N254	190*	1.5	0.4*	10
1N255	380*	1.5	0.4*	10
1N256	570*	0.95	0.2*	20
CK846	100	3.5	1.0	2
CK847	200	3.5	1.0	2
CK848	300	3.5	1.0	2
CK849	400	3.5	1.0	2
CK850	500	3.5	1.0	2
CK851	600	3.5	1.0	2

All illustrations same size.   Ratings at 25°C unless otherwise indicated.   1N253 through 1N256 available to MIL Specifications.

RAYTHEON SEMICONDUCTOR DIVISION

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Newton, Mass.............55 Chapel St., Bigelow 4-7500
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Los Angeles: 5236 Santa Monica Blvd., NOrmandy 5-4221

Control ENGINEERING

OCTOBER 1958

Published for engineers and technical management men who are responsible for the design, application, and test of instrumentation and automatic control systems

Continued on next page

Control ENGINEERING

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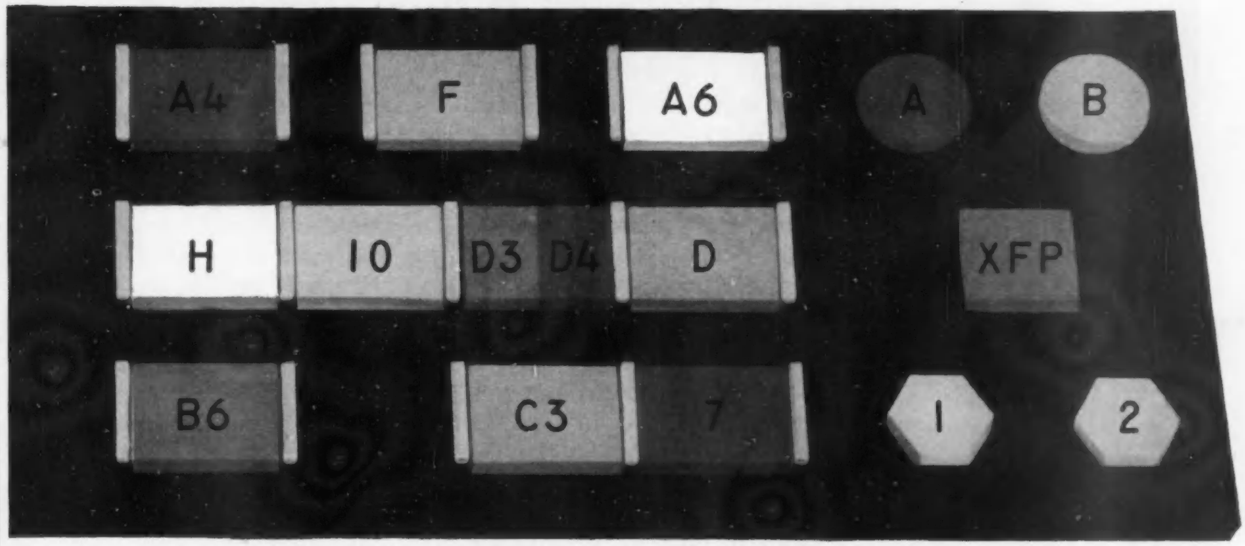
Switches have uses unlimited

have--Eye Appeal...
...Require Less Panel Area



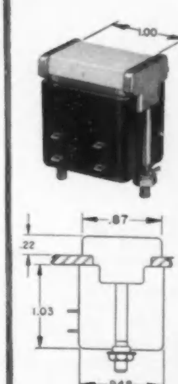
or 250 vac; or 3 amps inductive, 5 amps resistive, 30 vdc. *Send for Data Sheet 143.*

[The five buttons at the right of the main illustration are of the "50PB" series. Buttons of four shapes, in red, yellow, blue, green and white are available. *Send for Data Sheet 133.*]

MICRO SWITCH . . . FREEPORT, ILLINOIS
A division of Honeywell
In Canada: Honeywell Controls, Ltd., Toronto 17, Ontario

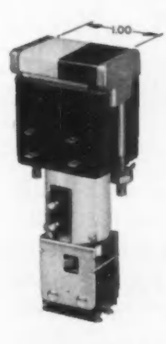
Consult with a MICRO SWITCH Sales Engineer.
Look in the Yellow Pages for location of Branch Office

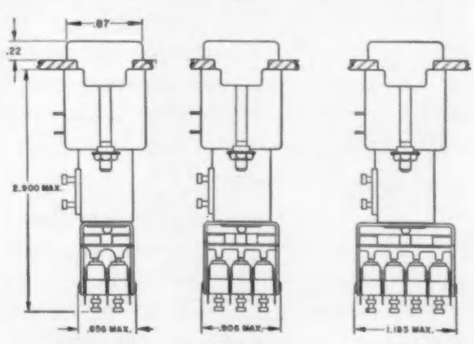
Honeywell
MICRO SWITCH PRECISION SWITCHES



"100LT1" Series
Matching indicating light assembly, without switch mechanism. Provides panel harmony. Has same button and lamp combinations, and same means of mounting as the complete switch assembly.

LT1 Indicating Light Assembly





2-Pole Unit   3-Pole Unit   4-Pole Unit

"100PB4" Series
Magnetically held "MAGSWITCH" contains a d-c solenoid whose terminals are electrically isolated from the lamp and switch terminals. With solenoid not energized switch action is momentary; with solenoid energized switch contacts remain transferred until electrically released. 2, 3, or 4-pole units are available.

CIRCLE 7 ON READER-SERVICE CARD

SHOPTALK

A sellout in reprints

The overwhelming popularity of the point-to-point positioning system articles ("31 Numerically-Controlled Point-to-Point Positioning Systems", CtE, January, February, and March, 1958) has resulted in a complete sellout of available reprints—over 5,000 copies. And since there has been no letup in demand to coincide with the exhausted supply, we've decided to reprint the articles again. Unfortunately, we must up the price from $1.25 to $1.50 for the complete 72-page set—the cost of reprinting from scratch is considerably more than letting the presses run a little longer initially to get the original batch of reprints. For those who want to fill out a complete set, a few individual copies of Parts II and III are still available.

A missive from Moscow

As mentioned in last month's *Shoptalk*, Editor Bill Vannah recently led a group of prominent U. S. control engineers on a control-and-instrumentation fact-finding tour of Russia. This issue bears the first fruits of this trip—Bill's initial letter from Moscow to CtE publisher Will Garey (see page 31). Future issues will bring forth complete reports of this group's findings.

Educator, engineer, and author

John E. Gibson (author of the phase-plane article on page 70 and many other articles in past issues of CtE) excells at presenting difficult concepts in a clear, concise manner, both to his students at Purdue (where he is associate professor of EE) and through the written word. After receiving his BS in EE from Rhode Island, he went to Yale for his master's and doctor's degrees, staying to become assistant professor of electrical engineering. While teaching at Yale, John found time to consult, to organize automatic control courses for Hamilton Standard and Sikorsky, and to work on his book, *Control System Components*, recently published by the McGraw-Hill Book Co. In the spring of 1957, John assumed his present position at Purdue. The graduate courses in advanced control system design and nonlinear automatic control he has developed are making Purdue a center for control system studies.

One last reminder

Keep your eyes open for the November issue; it will include CtE's contribution to the company-wide McGraw-Hill campaign showing the need for and benefits of modernization. Our approach: a special insert telling how to find opportunities for earning money through the addition of instruments and controls, plus case histories of money-making installations.

FEEDBACK

Reader's correction

To the Editor—

[Re "What About Digital Transducers?" Control Engineering, July 1958, pp. 94 ff]:

The 5-megacycle counter that you use (on page 98) takes as long to make a measurement as there are counts in the quantity you measure. If you measure something to 0.1 percent, there might be a 1,000 count before your measurement is digitally obtained. Therefore, the measurement can take as long as 1,000 counts. Since you count at a 5-megacycle rate, you cannot sample more often than 5,000 times per second. Unless I have misread your description of the counter in the article the above comments are valid.

The 1,000 samples per sec rate indicated in the article could be achieved by a device that sequentially adjusts one digit after the other. But such a device you describe separately and subsequently as the "third technique" [in the second following paragraph, page 98], where you choose a 1-megacycle rate of adjusting each digit to the correct value.

John M. Salzer
Director of Systems
The Magnavox Co.,
Los Angeles, Calif.

Dr. Salzer is correct; of course, the 5-megacycle staircase encoder can sample only 5,000 times per sec. Ed.

So where's the money?

To the Editor—

I have read the article by Lewis H. Young, "The Change at Cape Canaveral", CtE, June '58, pp. 79-85, and have noticed certain discrepancies that may lead other readers to gain the wrong impression about some of the systems under development at this range. Reference to the AZUSA system as costing $20 million and being too expensive for other ranges is incorrect and may be detrimental to the development contractor. The initial AZUSA system your reporter saw at Cape Canaveral is a breadboard system and did in fact cost over $10 million, including all studies and original experimentations. It must be remembered that AZUSA was the first system to reduce the CW phase comparison techniques to actual practice. This system is pushing the state-of-the-art in accuracy for trajectory measurements and has progressed amazingly over the few short years that it has been under study and development.

A second system, dubbed the Mark II, is a redevelopment which

will add significantly to the reliability of the system. A production model of the Mark II system, based on a single system production, is estimated at between \$2 and \$2½ million.

Another error was noticed in the SECOR comments. SECOR measures three or more slant ranges from widely separated, accurately known locations. From this information space position can be determined. Each DME (distance measuring equipment) does not determine direction, but a slant range from the ground site to the target.

In all, the article was very good, and I do not mean to criticize except that I feel that wrong impressions may be gained, especially in the case of the AZUSA.

Frank P. Stoklas, Manager,
CW Radar Engineering Unit
RCA Service Co.
Patrick AFB, Florida

Urges credit line

To the Editor—

We note with interest the item, "Controlling product purity from process measurements," on page 97 of the March issue. The author has failed to point out that the purification process which he describes is disclosed in U. S. Patent No. 2,748,849, issued June 5, 1956, to Porter Hart, assignor to The Dow Chemical Co.

It is strongly urged that such information be included in articles of this nature so that rights of the patentee and anyone who desires to use the process may be protected.

Porter Hart
Instrument Technical Services
The Dow Chemical Co.
Freeport, Tex.

Such rights should be protected. We think, however, that the late Mr. Garrett, the author, did not credit the inventor of the process because he wished to describe a method of control, not a method of processing. Ed.

This index is a publisher

To the Editor—

We would very much appreciate any information you could give us regarding the new "International Physical Index", which you reference on page 23 of the June 1958 issue of Control Engineering.

Missile Systems Div.
Raytheon Mfg. Co.
Bedford, Mass.

International Physical Index, Inc., 1909 Park Ave., New York 35, N. Y., has announced a series of scientific periodicals, "Expresses", based on

translations from 67 Soviet technical periodicals and transactions. Each Express will consist of complete articles, excerpts, abstracts, annotated titles, and occasional topical bibliographies. We have just received the first issue of Electronics Express and expect that the first issue of Automation Express will soon appear. Ed.

Clarifies use of "nonlinear"

To the Editor—

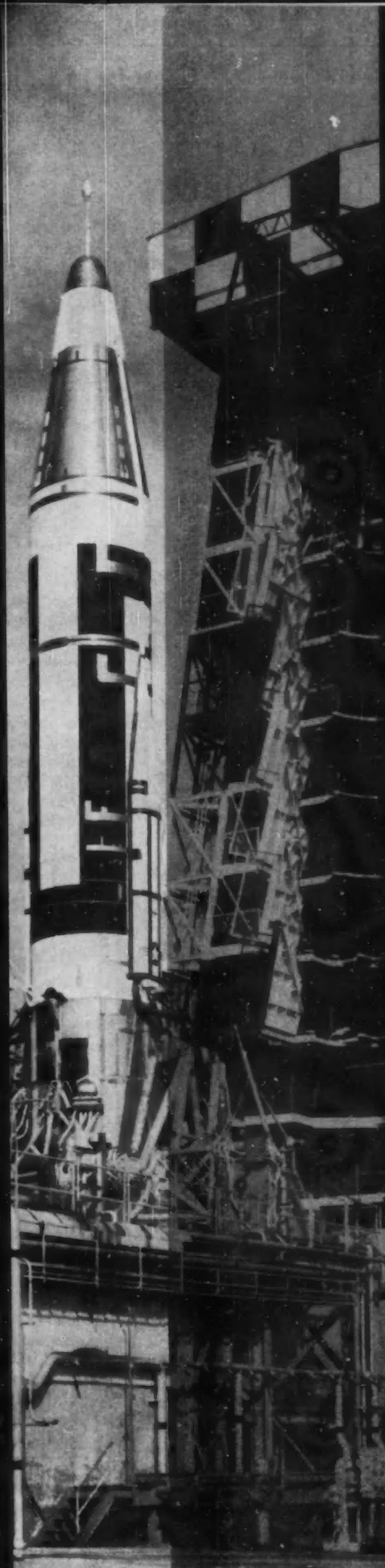
As usual I looked with great interest through the latest (August) issue of Control Engineering. One of the most important parts I felt was the description of the German controllers. Here, for about the first time a commercial controller is referred to as a nonlinear controller. Because control engineering as a technology is still on the move, new ideas are developing all the time. Hand in hand with these new developments go new terms and definitions. And here lies a real danger because when a new term is not used right from the beginning it will cause confusion forever.

The function of a controller is to operate upon the error between measured and desired values. The relation between output and input (error) can be represented by an integro-differential equation. For our conventional controllers this relation is in generalized form:

$$o = Ai + B\int i\,dt + C\frac{di}{dt}$$

where o is the output, i is the input, and A, B, and C are constant coefficients. This is a linear integro-differential equation. It remains linear when higher order integrals or derivatives of the first degree with constant coefficients are added. It becomes nonlinear as soon as one of the terms appears with a higher degree (squared for instance), or if one of the coefficients is not constant but depends in value and/or sign upon one of the variables of the control system or upon time.

It is here that the terms linear and nonlinear controller have their origin. What is in the black box between output and input is only of practical importance. Seen in this light I understand from the descriptions of the German controllers that the Schoppe & Faeser, Joens, and Hartman & Braun controllers are linear controllers with a nonlinear amplifier. Only the Siemens is a nonlinear controller in



the true meaning because here the proportional band depends upon the magnitude of the error.

I cannot emphasize enough the importance of keeping these definitions clear. We may expect an expanding use of nonlinear controllers in the near future.

Jake E. Valstar
Manhattan Beach, Calif.

Adds view on digital transducers

To the Editor—

I enjoyed Mr. Kompass's article on digital transducers (CtE, July 1958). It goes far towards dispelling confusion and ambiguity on this subject. Probably the term digital transducer shouldn't be used at all. The point I try to emphasize in discussing these topics is that a transducer contains—

1. A sensor of the measurement phenomena.
2. A pick-off or translating device.
3. A storage and/or transmitter.

The information format and the operating mode of each of these elements could in principle be analog or digital. With this perspective one can then describe an existing transducer without ambiguity—and sometimes even make a more intelligent design decision in developing new ones.

Don Lebell
Consulting Engineer
Sherman Oaks, Calif.

Wants more on German instrument co.

To the Editor—

In the August issue, *Industry's Pulse* (page 62, first paragraph) deals with the growth of German control instruments manufacturers. Among the names you mention is "Eckardt". While we know people like Siemens and Halske, Eckardt is new to us.

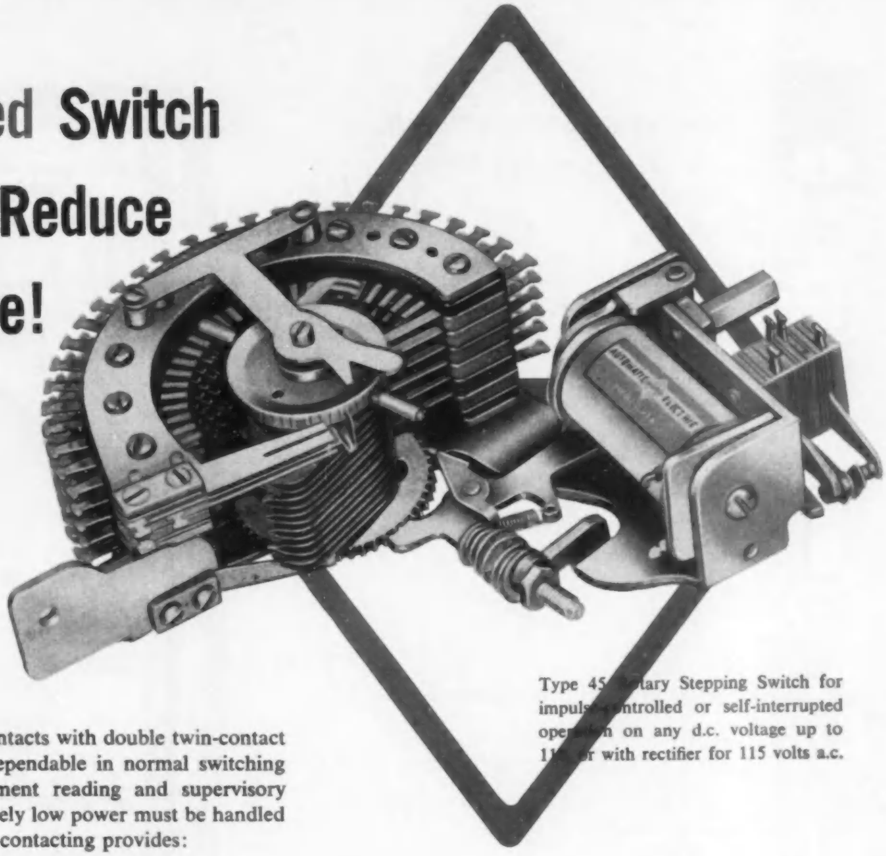
We would appreciate your checking the name and address of this company for us, and also what types of instruments this company makes.

W. E. Reed, Plant Manager
Metal Powder & Chemical Works, Inc.
Newark, N. J.

CtE's European Editor reports, via radio-teletype: "J. C. Eckardt Pragstrasse 72-82, AG Stuttgart-Bad Cannstatt, Germany:

"Manufactures pneumatic recorders and controllers for flow, pressure, and temperature and full range of actuators and pneumatic motors for butterfly and high-pressure valves." Ed.

Gold-Plated Switch Contacts Reduce Resistance!



Type 45 Rotary Stepping Switch for impulse-controlled or self-interrupted operation on any d.c. voltage up to 110 or with rectifier for 115 volts a.c.

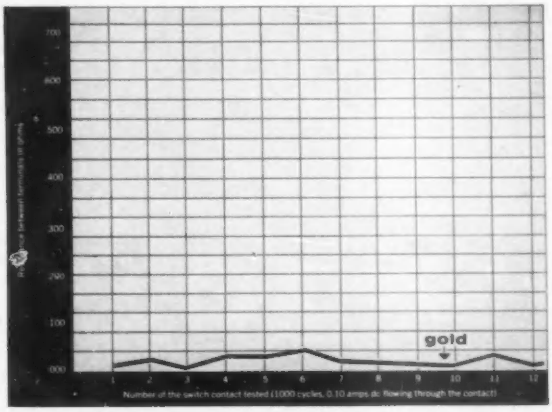
Standard base-metal contacts with double twin-contact design are absolutely dependable in normal switching circuits. But in instrument reading and supervisory functions, where extremely low power must be handled reliably, precious-metal contacting provides:

- *accuracy at lowest potentials*
- *low and constant contact resistance for the life of the switch*
- *freedom from spurious potentials which can be set up by base-metal contacts*

That is why instrument engineers specify gold-plated contacts for thermocouple monitoring and other low-power-level circuits – strain gauges – computers – and infrequently operated devices.

Precious-metal contacting costs more, of course. But with Automatic Electric's custom designing, it is not as expensive as you might think; on either Type 44 or Type 45 Switches, you can specify precious-metal contacts for instrument circuits only, with standard contacts handling the less critical circuits.

For full information on the use of stepping switches—*with or without* precious-metal contacts—ask for Circulars 1641 and 1698. Write: Automatic Electric Sales Corporation, Northlake, Illinois. *In Canada:* Automatic Electric Sales (Canada) Ltd., Toronto. *Offices in principal cities.*



Graph indicates resistances between terminals with gold-plated contacts. Measurements made under heavy vibration.

AUTOMATIC ELECTRIC

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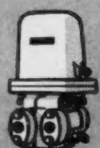
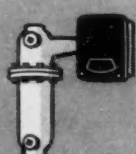
Indicating Motion-Balance Transmitters
...for flow, pressure, and level



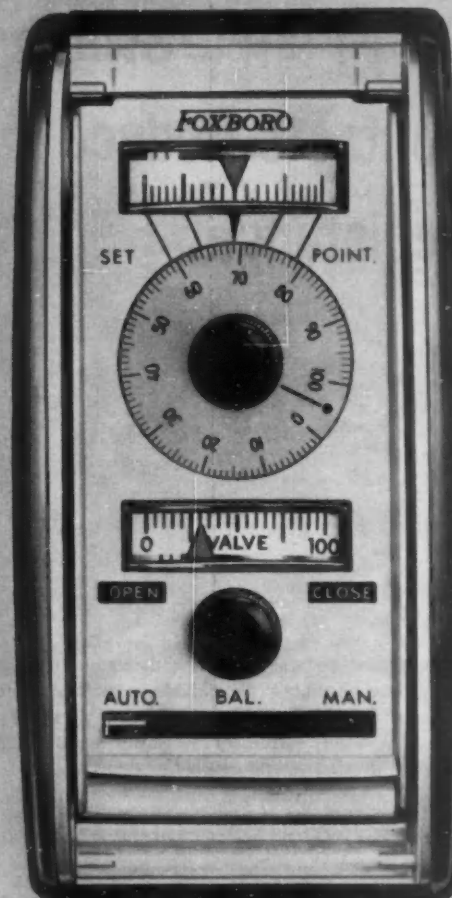
Low Displacement Force-Balance Transmitters
...for flow, pressure, and level

Thermocouple and Resistance Bulb Converters
...magnetic amplifiers...no vibrators
...no mechanical rebalancing



Displacer Level Transmitters
...force-balance for simplicity

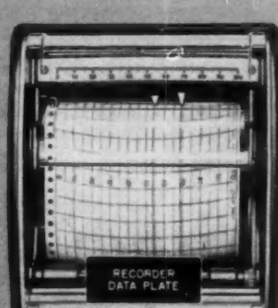
Control Valves
...electro-pneumatic and electro-hydraulic actuators



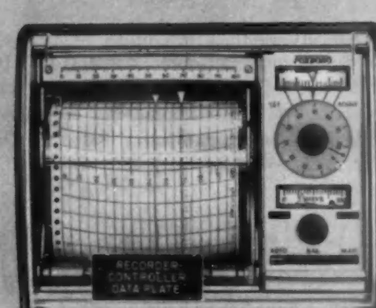
CONTROLLER
The Electronic Consotrol Controller (shown 4/5 actual size) concentrates all control and supervisory functions in one slim 3 x 6 inch case. Controller operation is entirely independent of recorder.

FOXBORO Electronic

REG. U.S. PAT. OFF.



RECORDER
Electronic Consotrol Recorders (shown ¼ actual size) use a simple, powerful pen motor which can be operated directly from transmitter signal without amplification. Available in 1 and 2 pen models.



COMBINED RECORDER-CONTROLLER
Electronic Consotrol housing design permits unequalled flexibility in panel arrangement. Recorders and controllers can be mounted separately in individual housings—or enclosed in a compound unit. Regardless of mounting, either unit pulls out independently.

 CIRCLE 17 ON READER-SERVICE CARD

C. Monroe Albright Jr.

helped stream analyzers grow

In 1945, when du Pont established the Applied Physics Section of its Engineering Research Laboratory to probe the mysteries of analysis instrumentation, a young du Pont engineer whose background in instrumentation was hardly impressive at the time was vigorously writing memos urging the project. During the previous months that surveying instrumentation had been his responsibility C. M. Albright Jr., had found a critical need for some place in the company to experiment with instrumentation, to try out new devices, and to follow basic studies that might lead to new ideas.

Albright joined that new section in 1945 as a supervisor working under Vic Hanson (CtE, Nov. '56, p. 21). And during the next 10 years he proceeded to build from scratch a background as a specialist in analytical instrumentation for on-stream measurement.

Monroe Albright's entrance into the instrumentation field was almost by chance. A mechanical engineering student at Cornell (BSME, 1938), he switched to electrical engineering for graduate work and majored in communications, earning a MS degree from Cornell in 1940. Albright hoped to work for one of the growing electronics companies but when none of them seemed anxious to hire young engineers, he accepted an offer from du Pont.

His first assignment was in the Field Industrial Engineering Group, where "they tried to make a chemical engineer out of him". He then went to the Remington Arms Div. as a mechanical engineer and concentrated on tool engineering. In 1944, he was assigned to a highly classified project (still on the secret list even today) which involved designing, building, and operating a semi-works plant.

Early in 1945, he was transferred to the consultant organization of du Pont's Industrial Engineering. When this department discovered that he was still a subscriber and reader of electronic magazines, they assigned him to work in the field of instrumentation.

While in this assignment Monroe Albright surveyed the field of instrumentation in general and at du Pont in particular. He found the technology in the infant stage. There were few analytical instruments available; most of them were untried in commercial operation. Du Pont, for example, had only two infrared spectrometers in the entire company; thermal conductivity measuring devices were short-lived because of frequent filament failures; ultraviolet analyzers were simple but so unstable they couldn't be used in a process. Only the pH meter was established as a practical device.

As early as 1947, Albright envisioned an automatic chemical factory, automatic from receipt of raw materials to shipment of finished product, and controlled at every step by analytical instrumentation. He conjured up a list of 12 instruments he felt the chemical industry needed for on-stream analysis.

Some of these have since been perfected in the Applied Physics Section or by suppliers. Albright himself was most closely associated with perfecting an ultraviolet analyzer: he made it stable, increased its sensitivity by a factor of 10.

Proof of his acquaintance with the broad field of analytical instrumentation was the request that he contribute to the *Process Instruments and Control Handbook*. Albright wrote the section on chemical composition and prepared the comprehensive foldout tables in the rear of the book, entitled "Instrumental Techniques for Chemical Analysis".

This ability to see the broad view impressed du Pont's management. In 1956, Albright was appointed assistant director in charge of research at the Mechanical Development Laboratory, where such areas as machine materials, mechanical research, and electromechanical research are studied. One project under Albright's wing: building a digitally controlled milling machine.

Early this year, Albright was again promoted, this time to staff assistant to the technical director in the Engineering Department, a position that serves as a training ground for broad management. This summer he went back to his alma mater, Cornell, for a special six-weeks management course. Now he's working in areas that afford the wider view of engineering and research, such as budgets and personnel.

At home, Albright is still a hi-fi enthusiast, a carryover from his electrical engineering days at college. And along with his five-year-old son C.M. III, he's a devotee of sailing. Any remaining spare time is spent reading a variety of books from action-packed detective stories to the classics.

WHAT'S NEW IN CONTROL

ELECTRICAL MEASURING INSTRUMENT PRODUCTION

From July 1, 1956 to June 30, 1957

Type	Quantity (units)
Regular Panel Instruments	1,667,678
Ruggedized Panel Instruments	387,509
Switchboard Instruments, Regular	136,875
Switchboard Instruments, High Shock	12,888
Direct Reflecting Recording & Controlling Instruments	99,050
Self Balancing Indicating, Recording & Controlling Instruments	46,304
Aircraft Instruments	161,259
Portables	21,878
Small Portables	32,178
Miniature Portables	72,849
Portable Standards	14,670
Laboratory Standards	1,711
Instrument Relays & Contact Making Instruments	99,357
Miscellaneous Instruments, Not Listed Above	24,065
Total	2,778,271

Electrical Instrument Survey

U. S. Dept. of Commerce's new approach to collecting instrument industry statistics (CtE, April, '58, p. 86) produced more results last month. Preliminary data on an electrical measuring instruments study was released by the Scientific, Motion Picture & Photographic Products Div., Business & Defense Services Administration.

The tabulation (above) is based on a functional classification of the instruments rather than conventional Standard Industrial Classifications. Dept. of Commerce analyst Louis A. Edelman says the data is expressed in terms of basic instrument units which he defines "as an assembly of parts necessary to form a self-contained unit for performing a measuring, controlling, or recording operation. A basic unit may be either used as a complete measuring device in itself, or incorporated as a component of a packaged instrument or instrument system which may contain two or more different functional groupings."

The complete study, including analysis and interpretation, will be released later this year.

TRANSIENTS IN CONTROL

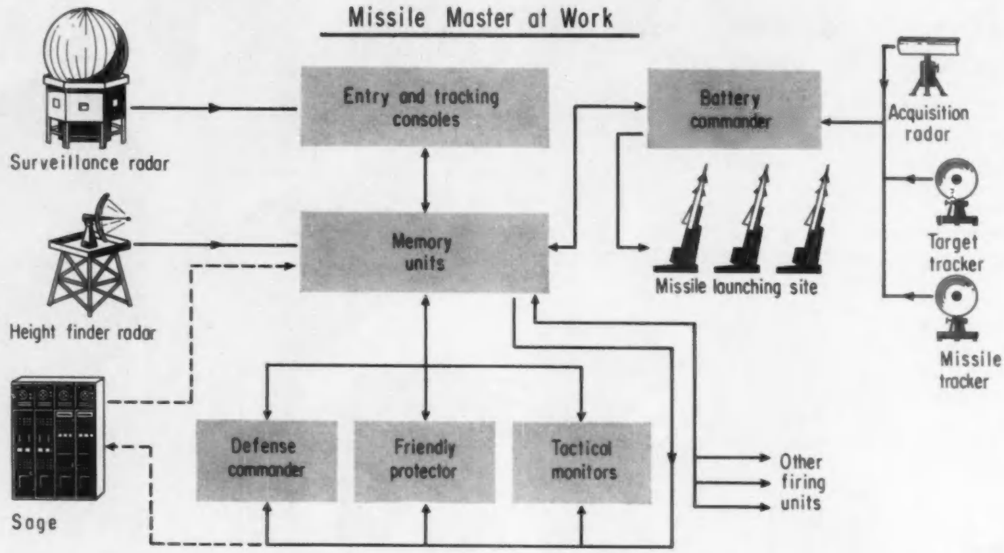
Unique dock crane, being built to handle ship cargo containers, permits automatic selection of location on board the ship. Because crane operator cannot see the container after it has entered ship's hold, the crane uses a synchro transmitter to report vertical position in relation to desired position to the operator.

•

What may be first process plant operated completely by remote control is being instrumented at Abqaiq, Saudi Arabia. Arabian American Oil Co. is converting a manually operated gas-oil separating plant (GOSP) to one controlled by radio-telemetry from a base station 20 miles away. Cost of converting the $1,500,000 plant is about $200,000.

•

First "platformless" inertial guidance system is being developed by Ford Instrument Co. for Weapons Guidance Laboratory at Wright Air Development Center. Main purpose of designing the "no-gimbal pure integration inertial guidance system" is to get a large increase in accuracy while reducing size and weight of the system. First phase of contract is for study and preliminary design.



What Makes Nike Run?

Here's how the Army's first electronic information system coordinates defense in Baltimore-Washington area, broadcasting symbology and target information to firing units.

Guarding the key Baltimore-Washington area against enemy air attack is the assignment of the 35th Artillery Brigade (Air Defense), which has thrown up an oval ring of 20 Nike missile installations around the two cities. Last December, the 35th got an electronic helping hand to coordinate the defense when The Martin Co. turned over to the Army an information display system called Missile Master. Last month Missile Master completed its first nine months on the job. And the artillerymen of the 35th Brigade are enthusiastic about it. Said Commanding Gen. Charles Dunn, "It works even better than we expected."

Missile Master's main job is to keep everybody in the widely dispersed brigade (some firing units are 90 miles apart; most are at least 30 miles from brigade headquarters at Fort Meade, Md.) informed about what's happening every instant during a raid. To do this, the system generates a symbology (a variety of easy-to-read symbols) which is placed automatically over attacking aircraft blips on radar 'scopes, and broadcasts it to a variety of consoles at brigade headquarters and to each battery command post.

After the nine-month evaluation period, General Dunn sees Missile Master, designated in Army jargon the AN/FSG-1, as a target selection and fire distribution system. It's not a centralized fire control system. "The battery commander at the firing unit still has the responsibility for picking the target and firing the missile," General Dunn explains. "But now, every battery commander knows who is going after what targets every minute."

The system works 24 hours a day, manned by a special army unit—the 12th Detachment (Air Defense Operations), which is attached to the 35th Brigade. Word of hostile aircraft approaching the 35th's defense area is flashed to the control room of the Missile Master by the Air Force. At present this warning is sent by voice line; but when SAGE starts operating, transmission will be automatic.

Position of each plane as reported by the Air Force is plotted at the operations center. Later information is retained in analog memory units and then broadcast to each of the firing units. The 12th Detachment starts tracking the target with its own radar equipment at Fort Meade, comparing its data with that supplied by the Air Force and correcting for changes in the target's position. These changes are continually transmitted to all firing units.

At the Nike sites, the batteries also have acquisition radar units that pick up and track the targets and compare this locally acquired data with the symbology broadcast by the Fort Meade control center.

When a battery commander selects a target and locks his tracking radar on it, the word is flashed automatically to Missile Master, which then broadcasts this information to all units.

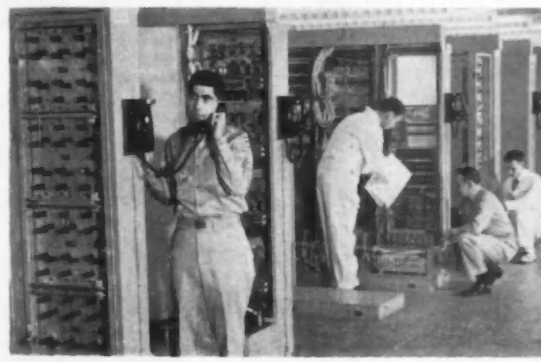
In the symbology used, a hostile plane is represented by a half-circle around the radar blip, a friendly plane by an out-of-focus spot. When a battery selects a specific plane as a target, a full circle then surrounds the corresponding blip.

At Fort Meade, brigade headquarters keeps abreast of the tactical situation in the "blue room", so-called because it is illuminated solely by blue lights, human engineered to make reading radar 'scopes easy. The 12th

Blue room of first Missile Master installation at Fort Meade controls target selection and fire distribution of Baltimore-Washington defense area. Next unit is scheduled for New York.

Closeup of radar tracking consoles. With tracking stick, soldier moves symbology over radar blip, then transmits position data to memory units. Trackers are a key human link in the input part of the system.

Friendly protector's console (in foreground) shows location of all friendly aircraft in area. Behind it are tactical monitors who keep abreast of the status of each firing unit, pass along orders from the defense command.



Part of the pallets in the equipment room where Signal Corps technicians and Martin Co. personnel (who perform contract maintenance) keep an eye on functioning of electronic components.

Detachment's blue room has three rows of consoles. In the front row are six tracking consoles, where operators sit and track assigned targets, sending position data to the memory units.

In the second row is a double console for two surveillance and entry officers. The S&E officers maintain contact with the Air Force, assign channels and channel numbers to the targets, assign targets to the trackers, and supervise the trackers. On each side of the S&E officers are height-finder radar 'scopes that report altitudes as the height finder selects targets in numerical order.

The third row holds five consoles: one for the operations officer who directs activity in the control room, three for so-called tactical monitors who maintain contact with the firing units (each officer monitors one-third of the firing units; these consoles report at every instant the condition of each of the assigned firing batteries), one for the "friendly protector". His job: to keep any firing unit from selecting a friendly airplane as a target.

The defense commander operates from a sound-proofed room separated from the blue room by a glass wall. His console is the most versatile of the lot. By pushing the proper button, he can see almost anything he wants: the position of hostile planes, hostile planes at a certain altitude, the target of a particular firing unit, etc.

On the defense commander's 'scope, auxiliary information is presented in a dot code near each symbol; some dots are located above the symbol, some below it, and some on each side. This code indicates such information as the plane's altitude, its status (hostile or friendly), etc.

Targets, both friendly and hostile, are put into the Missile Master system by the S&E officer. As soon as he is advised that a flight of aircraft has been identified, he starts assigning electronic channels to the aircraft. To do this, he pushes a "NEW" button. This sets aside the first available channel in the system for a specific plane (or close-flying group of planes). Channels may be in three conditions: 1) available for tracking; 2) tracking local; or 3) tracking SAGE.

Defense commander watches tactical situation from this console. Controls at left and in front of officer permit him to select a variety of specialized conditions.

Pushing the NEW button also generates a circle symbol at the geometric center of the 'scopes. The S&E officer moves that circle with his tracking stick to the radar blip representing the aircraft. When the circle is over the blip, he pushes another button to send slant height and azimuth data into the memory units.

And, a push on another button directs the height finder to search for the target just entered into the Missile Master system, granting it a priority over other targets that have been tracked before.

The S&E officer also sends to relay memories auxiliary data about the target: whether it is hostile or friendly; whether it is a flight or single aircraft; how many aircraft in the flight.

Finally, the S&E officer then assigns the target to one of the six trackers to follow. All this takes only a few seconds. And the S&E officer is ready to select a channel for the next target. Meanwhile, the position data

. . . tactical officers dispatch orders by pushing buttons . . .

in the analog memories and the auxiliary data held in the relay memories are broadcast to consoles in the third row, the defense commander's console, and all battery consoles.

At the tactical consoles, a series of lighted switches tells the officer the status of each firing unit assigned to his supervision.

The monitoring officer can send three instructions to batteries by pushing one of the three buttons, marked *E* (engage target), *H* (hold fire), and C (cease engagement).

The defense commander at his console can choose a priority target after reviewing the tactical situation. His order causes the half-circle symbol around blip to blink on and off.

All orders from the defense commander are relayed to batteries through the tactical officers. These orders usually are limited to choosing priority targets, assigning targets to batteries when necessary, or telling a firing unit it has zeroed in on a friendly aircraft. In most cases, actually selection of the target is left to the battery commander. (Major William A. Burt, executive officer of the 12th Detachment, explains why: "We might assign a target to a firing unit which it cannot see with its radar because of a geographic condition or because of ground clutter. And a battery commander cannot hit what he cannot see. This way, no BC will choose a target his tracking radar cannot see.")

Behind the blue room at Fort Meade is a large air-conditioned room housing the electronics that make Missile Master work. Key racks:

- stepping switches that program the channels
- analog computer to convert slant height, azimuth, and range into x- and y-coordinates and into ground position
- analog memory units to store position data
- relay memory units to store the auxiliary data
- an analog-digital-converter. All data is reviewed as analog information, but broadcast as digital information and then reconverted at the firing units.

Missile Master relies on a massive group of stepping switches. The exact number of channels is a secret (since it indicates how many aircraft could be reported by the system), but each channel handles nearly 40 different

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CIRCLE 21 ON READER-SERVICE CARD

functions (typical ones: x- and y-position, hostile or friendly, altitude, controls for changing information, whether channel has priority, etc.).

Each console (of the ones already described) has eight stepping switches in parallel associated with it; and each switch has 12 decks. This is what gives the system its versatility and flexibility: each console can examine any channel for a variety of functions.

The analog memory is composed of feedback integrating amplifiers. There are seven associated with each target, four to retain position data, one for altitude and two for velocity. Missile Master uses a manual-rate-aided system for tracking; that means the computer velocities are integrated to update position data.

Prime contractor Martin Co. chose analog memories so that the system could use an existing tracking subsystem developed by Airborne Instruments Laboratory. But Martin sees two additional advantages of the analog memories: they lack granularity; and because the memories are analog, position data can be up-dated or read out at random.

Auxiliary data, on the other hand, is retained in relay-type memories.

Because of the complexity of the Missile Master system, the Army has a maintenance contract with The Martin Co., whose engineers and technicians are on duty 24 hours a day to service the complex gear. At present Martin is also helping to train operators for the system.

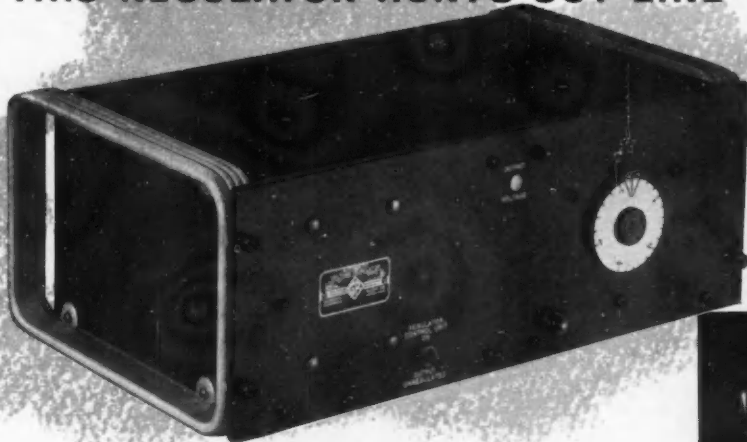
General Dunn points out a personnel paradox with Missile Master. The system requires a high level of competence from the people who use it and considerable training. Yet, as he puts it, "How long can a soldier do nothing but scan a radar 'scope?" General Dunn feels that one or two years may be all a soldier can stand of such duty.

The 12th Detachment uses both men and women for the radar tracking job. The percentage of officer personnel is high—almost one officer for every three enlisted men—because crucial split-second decisions of a tactical nature have to be made at several places throughout the blue room at the same time.

Despite these reservations, the artillerymen of the 35th Brigade like Missile Master. The Army is going ahead with its program to equip other key potential U.S. target areas with the system. Next installation: the New York defense area.

—Lewis H. Young

THIS REGULATOR HUNTS OUT LINE-VOLTAGE PROBLEMS



The HUNTER...

... a General Radio Type 1570-A Automatic Line-Voltage Regulator . . . consists of a ball-bearing Variac, "buck-or-boost" step-down transformer to multiply Variac power rating, and a proportional-control servomechanism to automatically position the Variac.

The application of proportional control servomechanisms to voltage-regulator design offers many operating advantages. These include full accuracy of ±0.25% at any load power factor and considerably less weight and cost per KVA than other types. Overall system efficiency is 98%.

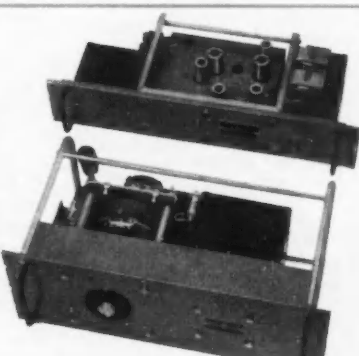
G-R TYPE 1570-A AUTOMATIC LINE-VOLTAGE REGULATOR

- 115v, 60-cycle models for bench, rack, or wall mounting . . . $490; 230v models . . . $510
- 3 units may be used to regulate legs of a 3-phase circuit
- 50-cycle models also available

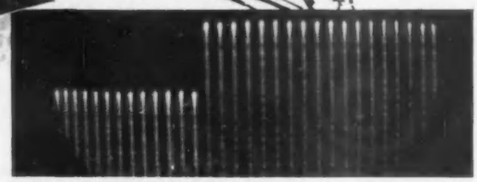
Militarized Model, 50 and 60 cycles Type 1570-AS15, $670

. . . meets MIL-E-4158A requirements. Control circuit is on one panel; Variac, buck-boost transformer and servo-motor are on another.

Write for Specifications.

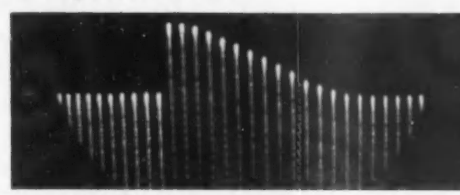


Write for the G-R Automatic Regulator Bulletin For Further Information



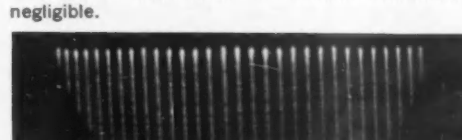
The HUNTED . . . any change from constant output voltage, such as the 2% change in 60-cycle voltage shown above. The Automatic Voltage Regulator will maintain output constant within ±0.25% for input variations up to ±10%, with 6 KVA power capacity. The same model can also be easily connected to handle ±20% input variations at loads to 3 KVA (accuracy ±0.5%). Short period overload rating is up to ten times steady-state rating.

A special model, the Type 1570-ALS10, is available to correct ±5% voltage variations and is capable of handling loads to 12 KVA.



The CHASE . . . begins immediately with a sensing of the line-voltage variation. An error voltage, proportional to the variation, is fed to the Regulator's two-stage balanced amplifier, then applied in push-pull to a thyratron circuit controlling a two-phase motor that drives the Variac. Correction takes place at the rate of 10 volts/second (in oscillogram above, 2% change is corrected in 12c or 0.2 sec).

This instrument is a true proportional control system, rather than an off-on device. Hence, correction is smooth — "dead zones" are absent. Overshoot is negligible.



and the KILL . . . is accomplished quickly and neatly. No waveform distortion is introduced by the regulator, nor are there any power-factor restrictions. There are no relays to cause transient pulses or chattering.

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WHAT'S NEW

Operating Guide Computer On-Line in Esso Refinery

An operating guide computer system has gone on-line at Esso's Baton Rouge refinery on a catalytic cracking unit. Incorporating a LGP 30 general purpose computer, the system measures 160 variables, then computes 27 operating guides such as catalyst circulation rate, carbon burning rate, and material balance.

In addition, it serves as an automatic data logger, printing out off-normal conditions, furnishing, on demand, hourly and daily log sheet summaries of process operation.

One newsworthy thing about the installation is that it represents L&N's entrance into the digital field. Up to now, the Philadelphia instrument company has concentrated on analog devices and analog computers. For the Esso operating guide, L&N developed a special analog-to-digital converter, had to learn digital techniques.

L&N apparently plans further forays into process control with digital techniques. A few months ago the company signed a pact with Philco to use Philco's transistorized computer developments in future process control applications. (See page 50.)

The Esso-L&N operating guide computer is another step towards computing-control in the process industries. Other companies that have also taken a first step:

► Thompson - Ramo - Wooldridge Products, which has sold a process control computer, the RW-300, to the Texas Co. to control a polymerization process.

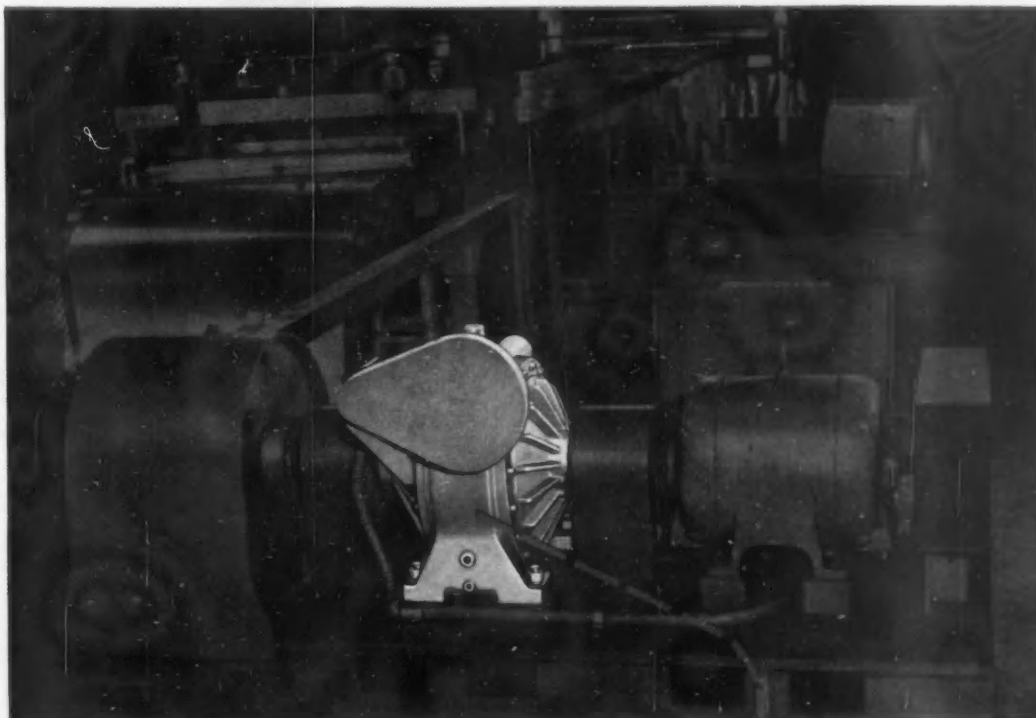
► Daystrom Systems, rumored to have installed an operational information system at a processing plant.

► The recently formed Genesys Corp, which has developed a computer system for chemical and petroleum processing plants.

Univac's Automatic Program

For Univac users with a programming problem, Remington Rand showed off a new solution last month. Called Flow-Matic, the remedy is an automatic programming system that cuts programming time 90 percent.

With the new system, high school girls, trained for a few weeks, insert instructions in English instead of in the machine's own difficult (for humans) language. From such orders, the computer prepares its own program, using a compiler tape to search out subroutines in a stored library.



Processing line speed control no problem

. . . thanks to Cleveland Speed Variator

At Armco Steel's Middletown Works, one rugged 7K6 Cleveland Speed Variator provides infinitely variable speed progressions for one of their many steel processing lines.

This electrically remote-controlled unit is shown driving the line's conveyor pay-off reel station. All Clevelands feature simple, precise construction which makes for a compact, quiet-running, instantly-adjusted drive.

If variable speed drives are indicated on your production processes, then Clevelands are the logical choice. Write today for illustrated Bulletin K-200 for complete specifications, sectional drawings and rating tables on the full line of Cleveland Speed Variators.

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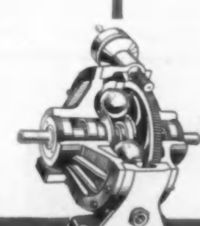


HOW IT WORKS

Power is transmitted from input shaft to output shaft through alloy steel driving balls which are in pressure contact with discs attached to the two shafts. Relative speeds of the shafts are adjusted by changing the positioning of the axles on which the balls rotate (see cutaway view, right).

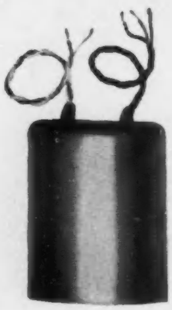
CLEVELAND SPEED VARIATOR

HONEYWELL Recorders and Components

for electronic use

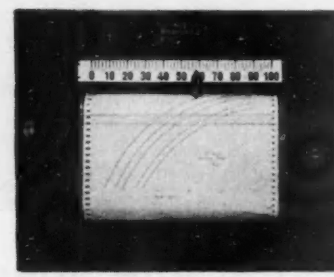
These instruments and components can serve scores of measurement, control and servo applications in your research and production work. Honeywell's world-wide engineering and service organization can give you valuable help in applying these products. For details, call your nearby Honeywell sales engineer. He's as near as your phone. Or write for the Honeywell Composite Catalog.

MINNEAPOLIS-HONEYWELL, Wayne and Windrim Avenues, Philadelphia 44, Pa.



SHIELDED LOW-LEVEL TRANSFORMERS

For input or coupling circuits, these transformers faithfully handle low-frequency a-c or chopper-modulated d-c signals of from 0.0005 to 200 millivolts. Highly effective electrostatic and magnetic shielding. *Write for Specification S900-1.*

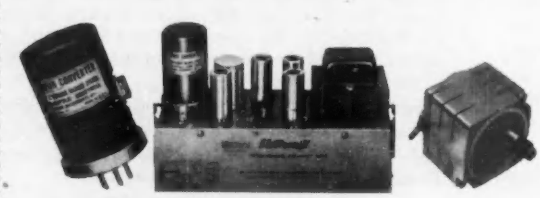


BROWN INSTRUMENTS

For measuring, recording and controlling temperature, pressure flow, liquid level and many other variables. The line of *ElectroniK* potentiometers includes special models for research work . . . such as the Function Plotter, Duplex Function Plotter, Extended Range Recorder, ¼-second Pen Speed Recorder, Adjustable Span Recorder, High-Impedance Recorder, and Brown-Rubicon Precision Indicator. *Write for Catalog 1561.*

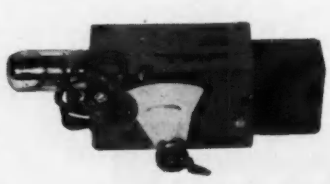
***ElectroniK* NULL INDICATOR**

The modern successor to the spotlight galvanometer, it's ideal for either lab or production work. Resists vibration, responds quickly, takes heavy overloads without "loss of spot." *Write for Data Sheet 10.0-12.*



BROWN SERVO COMPONENTS CONVERTERS, AMPLIFIERS, MOTORS

These components, proved in thousands of *ElectroniK* instruments, are available as individual units. For remote positioners, null balance circuits, analog computers, co-ordinate translators, servo loops. Order in small quantities for prototype development, or by the thousands for production use. *Write for specifications.*



***Electr-O-Vane* PRECISION SWITCH**

Less than 2 gram-inches of torque actuates this high-precision SPDT switch. Switching action occurs with from 0.00025 to 0.0025 inches of actuating lever movement. Use it as a non-loading limit switch, cutoff switch, or no-load safety switch. *Write for Specification S800-1.*

Honeywell

First in Controls

Letter From Moscow

Here's the first technical report on Soviet instrumentation and control written by an American expert visiting Russia. Editor Bill Vannah sent Publisher Will Gary this report from Moscow, where Bill was heading the American Automatic Control Council's 13-man delegation. The group visited Soviet chemical, petroleum, computer, metalworking, machine tool and instrumentation plants and institutes. In this letter, Editor Vannah:

- Describes the instrumentation on the Soviet's first atomic power plant
- Ranks Soviet industry by their use of measurement and control
- Warns about Russia's plans to dominate the international control market

Hotel Ukraine
Moskva, CCCP

Dear Will:

Today we inspected the 5,000-kw atomic power plant at Oduinsk, completed in 1954. The plant is used for irradiation experiments, as well as to produce useful electrical power. It's a pressurized water reactor type consisting of a cylinder of graphite 150 cm in diameter and 117 cm high, pierced with 128 holes containing:

- 550 kg of uranium, 5 percent of which is U-235, arrayed around water tubes
- two "scram" rods made of boron
- 18 manually controlled rods made of boron
- four servo-actuated continuous control rods made of boron

The controllable reactivity is about seven times the reactivity with rods withdrawn—very conservative. The active region is cooled with water at 190 deg C and 100 atmospheres; the heated water, in turn, generates steam in the secondary loop.

Throughout, the design is very conservative—up to the instruments and controls. Where we would use logarithmic activity channels, "scram" from a period signal, and have lots of interlocks, they have designed this reactor to have a large thermal feedback coefficient and use only linear activity channels. No safety channels and no interlocks. What's more, cooling water connections and the tubes through which the control-rod cables pass make a veritable rat's nest at the top of the reactor. It's an example of brute force, no finesse, no ultimate automatic safety channels—but it works and it produces power.

This approach our visiting group has called "cliche number 67". We find it in almost every plant, but we find no cause to be smug. For the Russkies array concentrated engineering, economic, and material force behind every technological salient that they rate as important. "Only forward" is the slogan, whether accompanied by vodka or by a study of engineering drawings.

Where are they going? What industries are they pushing hardest? The second question is easier to answer. It is answered by ranking industries by the degree to which they have adopted measurement and control. Up through this year, industries ranked this way on an automatic control index scale:

- Power, especially hydro stations
- Steel, especially blast furnaces
- Oil, especially refining
- Heavy machines, especially for automotive and aircraft plants
- Chemicals

And now they've decided to put full steam behind their infant plastics and synthetics industries, largely, I think, to satisfy the demand for consumer goods; for the populaces of major cities have money to burn and a desire for more and better things.

The productivity push, we are told, will cause the measurement and control industry in the U.S.S.R. to increase 2.8 times between '56 and '60. If the control manufacturing plants we have seen are anywhere nearly typical, the Soviet Union could easily enjoy the increase (note that it's about twice the expected growth rate of our control industry). When you combine this growth rate with a price reduction in control instruments of 10 percent every three years, we have cause to sit up and wonder "where are they going?" The 10 percent figure applies to mass-produced control instruments. New control instruments, the Soviets say, experience a 44 to 50 percent price reduction in their first three years of life.

This has some ominous overtones. If you take an instrument that has an average virile sales life of eight years, then reduce its price 45 percent in its first three years, another 15 percent in the subsequent five years, and at the same time, increase its production five times, sell it to China, Czechoslovakia, India, Argentina, and 26 other countries, isn't it clear that you're going after the international control instrument markets? That's what the Russians are doing!

How? Mass production (that's supposedly our specialty) and lower prices.

Proof? We saw a production line for electronic recorder-indicators for the process industries turning out 110 instruments every 24 hours (only one 7-hour shift because the mechanical shop could not keep up with the production line). Selling, on the average, for 2,000 rubles, these instruments are directly competitive with U.S.A. products if the exchange rate is four rubles/dollar. This price allows a 6 to 10 percent profit. But, of course, the Soviets can adjust their exchange rates and, therefore, their profit ratios.

More proof? We observed a trend for each "instrument" plant to concentrate into narrow product lines with an expected eventual result that one plant may have a complete monopoly for producing, say, eight-channel oscillographs. One in Leningrad, in fact, does. With a line that is only partially mechanized this plant has increased its production of eight-channel oscillographs by 2.17 times in seven years and expects a five-times overall increase from 1950 to 1960.

Here is a control industry with which we should become much more familiar than two handsful of men could in two weeks. It has set an objective: domination of international control markets. In rundown, poorly lighted, but mechanically well-equipped, buildings it is showing an impressing growth rate of products highly competitive with those made by the U.S.A. control industry.

They will go after our markets for

"bread-and-butter" products. Our recourse then would be two-fold: produce a high-quality product even more economically, and continually upset the market with entirely new products with a shorter product life than theirs.

I was going to give you a lot of details on design—novel little features. I was also going to explain how their designs have used mathematicians to a remarkable extent. I was going to discuss the pay structures in their control industry. Later, please; I'm running out of U.S.S.R. airmail stamps.

Bill Vannah

(For CtE's readers, Bill's "later" is the November issue which will feature a complete report on Soviet instrumentation and control.)

33 Raytheon Radar Units Now on Order at CAA

The Civil Aeronautics Administration (CAA) now has 33 long-range radar units on order from Raytheon Mfg. Co. The increase came with a new order for six units, at a cost of $2,710,000, for air route traffic control centers at Chicago, Memphis, Miami, Los Angeles, Phoenix, and Houston. Delivery will start in December.

McGraw-Hill Calls the Turn on Machinery New Orders

Six months ago the McGraw-Hill Dept. of Economics forecast an upturn in machinery new orders for the second quarter of 1958. This has now come to pass. It is a pleasure to report this fact, not only because the McGraw-Hill department is one of CtE's favorite and best qualified sources of economic data, but because of what the come-true prediction signifies for, among others, machine tools. Says McGraw-Hill:

"New orders booked in the second quarter 1958 ran 11 percent above the first quarter figure. Capital goods producers are more optimistic now about prospects for new orders than they were three months ago. On the average, they expect about 3 percent more new business over the next nine months than they forecast in April.

"Machinery manufacturers forecast a rise in new orders, after seasonal adjustment, in each quarter through the second quarter of 1959. New orders are expected to be 12 percent higher in the second quarter of 1959 than they were in the comparable three-month period this year."

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GPE Controls, Inc. is the result of a new idea—to bring you the products and the counsel of a coordinated, integrated service in control technology. It welds together the separate industrial control capabilities of several subsidiary companies of General Precision Equipment Corporation, and it brings you the sum of all these capabilities in one neat, easy-to-open package.

GPE Controls, a new name for Askania Regulator Company, provides a custom-tailored organization offering industry the full gamut of process control, systems for automation, computers and data-logging equipment, high-performance hydraulics, and mechanical and electronic computer components—the industrial services of Askania, Librascope, Kearfott, and Link.

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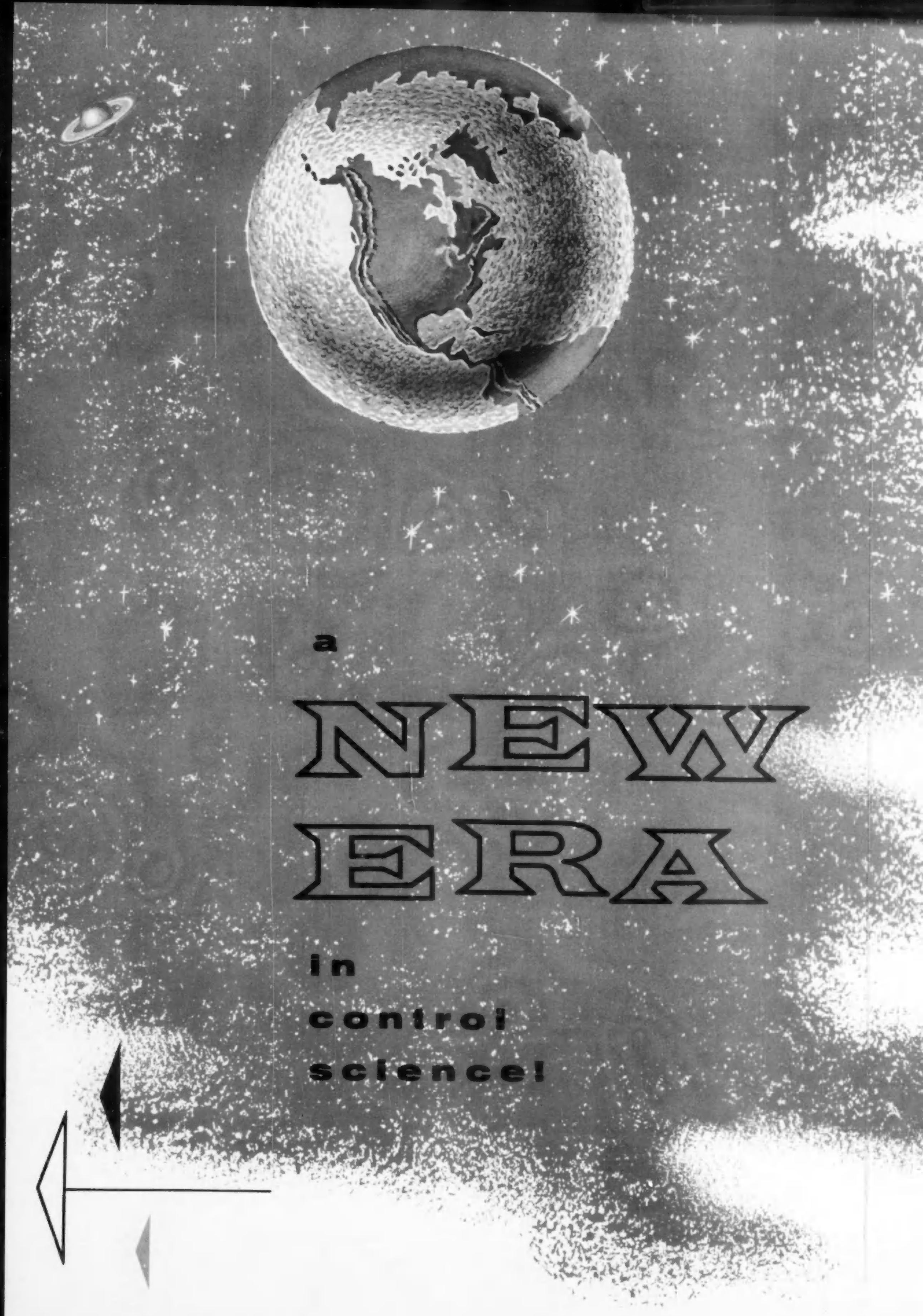
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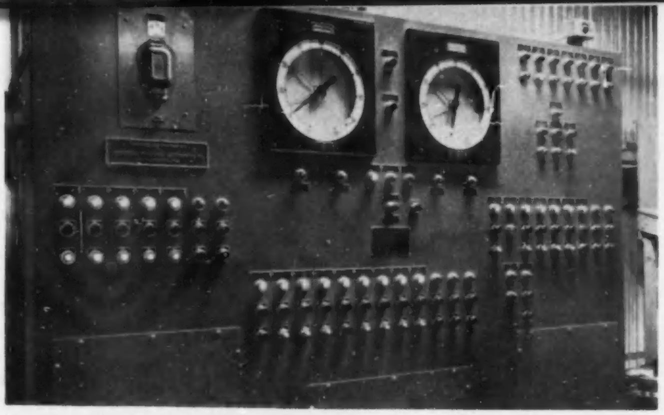

Crushing plant control panel with selector switch in center permits operator to set up desired conditions of operation in one motion.

Uranium Mill Controls Preview a New Look in Mining

Because the uranium industry is so new, there are few traditional approaches dictating how processing is to be carried out. As a result, this infant industry, already beset with keen competition, is sparking a revolution in the use of instrumentation and control in mining processing. The Homestake-New Mexico Partners uranium mill recently completed near Grants, N. M. is probably the biggest user of instrumentation and automatic control equipment in the mining industry. Industrial Physics & Electronics Co. installed the gear.

Widespread use of instrumentation here was called upon to solve a specific problem: to keep the plant labor force to a minimum. The $8 million mill is built close to the source of the ore, which unfortunately is miles from the nearest town. That meant the company would have to supply housing quarters for the labor force. Instrumentation, costing almost $130,000, was paid for immediately by the savings in buildings—housing that didn't have to be constructed.

To a control engineer in the chemical or petroleum industry, the design philosophies at this plant are not new. But in the mining industry they are revolutionary, says C. M. Marquardt, president of Industrial Physics & Electronics. For the first time in a mining operation processes are run from a central control panel by pushbuttons. There are five such units spread throughout the mill.

One panel (see photo) operates the crushing plant, which reduces the ore to a fine powder in either of three operations: 1) coarse crushing, sampling, fine crushing and storing in bins; 2) coarse crushing, sampling and storage in intermediate areas; or 3) fine crushing previously sampled ores. Although pilot lights tell the operator what equipment is required for each of these conditions, a simple selector switch permits him to set up the entire operation with one motion.

Grinding plant controls are also integrated into a single panel. The ore is weighed by pneumatic scales as it enters ball mills, then diluted to proper proportions by a flow recorder-controller.

Next step in the process is leaching in Pachuca tanks. Steam addition is automatically controlled to keep a constant temperature. After filtration the solution is then precipitated with sodium hydroxide to form a yellow cake. A rotometer-type flow meter measures the hydroxide solution; the pregnant solution is also automatically metered.

There's a unique control system, according to Marquardt, applied to the yellow coke four-hearth dryer. Using bias regulators the operator can set, on a central control panel, the ratio of fuel being fed to each hearth. The gas temperature in the third hearth is used as the basis for automatic control. A temperature profile is established from operating experience by the manual bias fuel flow regulators. Temperatures in the third hearth control the fuel supply to all of the four hearths (third hearth was chosen because it's the best insulated.

One control subsystem planned for the mill would have been the most unusual, but it failed to work out. The plan was to use a radioactive detector to assay tailings or waste products automatically. The big problem: to separate the "daughters" of

uranium—thorium and radium primarily. Although the technique for separating the radioactive but nonuraniferous daughters performed in the laboratory, it didn't work in the full scale plant.

But despite this one failure, the instrumentation and controls permit the Homestake mill to run with a labor force just two-thirds that originally planned before the automatic controls were decided upon.

—R. Bernick
McGraw-Hill News

Broadening Magnetics

L. A. Conference on nonlinear magnetics expands its coverage. 1958 attendance is double last year's registration.

The third annual meeting devoted to magnetics was the biggest and most successful held yet. Meeting in Los Angeles early in August, the 1958 Special Technical Conference on Nonlinear Magnetics & Magnetic Amplifiers reported its biggest turnout—800 people (more than double the number last year) and 31 exhibitors. And the group's new name—changed from the Special Technical Conference on Magnetic Amplifiers—indicates the broadening base of magnetics and their importance as devices in computers and control applications.

One of the most interesting papers to control engineers was that dealing with a "Control Rectifier" by J. D. Hardnden, General Electric Co. He described the control rectifier (CtE, February '58, p. 32), a semiconductor device that has nonlinear characteristics similar to magnetic amplifiers and thyratrons. According to the GE engineer, the device rectifies current carrying up to 30 amp at 300 volts. A control electrode turns it on and off. Time response is excellent; turn-off or turn-on time is less than one microsec. Voltage drop across the rectifier is only 0.7 volts.

Potential application of the device: as a static switch, where it can do the same job as a contactor or magnetic amplifier. Although the control rectifier itself is not magnetic, it can be used in control circuits employing magnetic coupling devices.

In one of the sessions devoted to computer magnetics, RCA's J. A. Rajchman presented a broader view of magnetic devices. He pointed out that magnetic storage devices were of outstanding value when large arrays were involved, when switching and

storage were intimately related, and when high reliability is essential.

In addition Rajchman described the parametron now being used by the Japanese in computers (CtE, Sept. '58, p. 53). With the parametron, he said storage is accomplished on the basis of phase; two cores per bit are required.

A French core storage device that also uses no diodes was described by three authors from Societe d'Electronique et d'Automatisme, France. In this arrangement, three cores are required for each bit.

Still another memory device, the twister, was discussed by Bell Telephone Laboratory engineers A. H. Bobeck and R. S. Title.

Other highlights of the meeting: magnetic servoamplifiers were compared by Z. H. Meiksin, Westinghouse Electric Corp.; an analog division circuit using magnetic components was described by W. McMurray of General Electric Co.; a cross-section of industrial activity covering amplifiers, servo stability and high temperature affects was presented in remaining sessions.

Complete proceedings of this meeting are available at a cost of $7 from The Special Technical Conference on Nonlinear Magnetics & Magnetic Amplifier—P. O. Box 2025, Downey, Calif.

—E. M. Grabbe
Ramo-Wooldridge Corp.

Wescon Booms

Busy days are back for West Coast control engineers; evidence is a record turnout which saw a diversity of components and heard a broad selection of technical papers.

The 1958 Wescon gave plenty of evidence that the good, busy days are coming back for the electronics-connected industries. The keepers of the expense accounts found money enough to send well over the expected 30,000 engineers (33,223) to the show and conference in Los Angeles in August.

During the four-day show, the aisles of the exhibit areas were consistently filled—in marked contrast to the light traffic noted at some technical meetings held earlier in this recession year. And the exhibitors—over 700 of them—were out in force, too; there were few—if any—"no shows" to leave dark gaps in the long rows of display booths.

Spirits were high. Talk of new con-

tract awards was heard everywhere. It was apparent that the attendees were in a buying mood, and inspecting the products on view with more than academic interest.

The magnitude of the exhibition was impressive and was especially gratifying to the West Coast segments of the industry. In a few years, they have seen the show grow to a size approaching that of the annual IRE Convention in New York. The feeling was that next year will see even greater participation by exhibitors—not only in terms of numbers but in the size of individual exhibits.

The emphasis at Wescon was decidedly on components and subsystems, reflecting the tendency of many systems-oriented companies to diversify into manufacture as well as design. Also, it seems to be more generally recognized that the success of a system depends not only on the ingenuity of its concept, but also on the proper choice of the hardware in it.

• **The conference papers**—The Ambassador Hotel was the scene of well-attended technical sessions, one of which was devoted to human factors in engineering. H. P. Birmingham of Naval Research Laboratory, covered the optimization of man-machine control systems. In the NRL approach to the design of man-machine control systems, the human is considered as a system component for the purpose of optimization. Birmingham described methods of compensating the electromechanical portions of the system to minimize the degrading effect of human noise, drift, varying gain and nonlinearity upon system performance.

Bell Telephone Laboratories' H. D. Irvin disclosed that the laboratory will build a special installation in Murray Hill, N. J. to evaluate performance of man-machine systems by providing realistic environments for the subjects.

Checkout testing was very much a part of other sessions, too. One meeting on military electronics included a plea by D. R. Proctor of Electronic Engineering Co. for timing standards. Test-system instrumentation has required the development of timing signals with specialized codes and formats. The speaker suggested the need for standard building blocks that will be compatible with the majority of system requirements.

J. I. Davis of Hoffman Electronics Corp. discussed reliability considerations as related to the test equipment confidence factor, with emphasis on the desirability of fail-safe procedures. He differentiated between factory, depot, and field test equipment. He described test methods using automatic programming and digital read-out displays.

—John Cooney

Reactor Accident Study Urges Wider Use of Safety Instrumentation

A year after the Windscale reactor accident, an investigating group offers some sober recommendations to assure the safety of other nuclear plants.

A seven-year-old reactor stands abandoned at Britain's Windscale atomic research station, entombed in concrete. "This monument to our ignorance" (quoting Sir Christopher Hinton, then director of Atomic Energy Authority's Industrial Group) points up a moral: if you don't know, instrument to find out.

Reading between the lines of the final report of the government investigating committee on the Windscale reactor accident shows that increased instrumentation could have prevented the release of radioactivity into the air.

It happened a year ago (last October). The pile was shut down for routine maintenance and for release of Wigner energy stored in the graphite core. During the release, the graphite is annealed by allowing the pile to diverge for a few moments with the air cooling shut off. The graphite heats up to a triggering temperature of 100 deg above the normal running temperature. At this point the graphite relieves itself of internal stresses imposed by distortion of its atomic lattice under bombardment by fission neutrons. Once the relieving action has started, heat released by the stored energy in the graphite sustains the action.

Although the reactor had been previously shut down some 30 times in its seven year life, on this occasion instrument readings of the graphite temperature led the operating crew to think that the self-heating process was drying out. A second divergence was initiated. This led to overheating in a portion of the pile not instrumentated. The heat spread undetected until the temperature reached a monitored position.

Even then, only one temperature recorder showed rising temperatures, but this was ignored because it is a normal trend during energy release. It wasn't until monitors spotted increasing radiation level in the cooling air passing up the stack to the atmosphere that the operating crew took remedial action. When nothing happened, the operators decided that a uranium fuel element must have burst from its aluminum can. While trying to locate

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RECEIVER Accuracy 30′ max. error spread Torque Gradient 2200 mg-mm/deg. Input Power .54 watts
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suspected elements, the scanning gear of the burst cartridge detector jammed because of the high temperatures. Emergency action—by the hazardous operation of removing fuel cartridges from the reactor for visual inspection —located no less than 150 channels jammed in the reactor and glowing red hot.

Operators could not use carbon dioxide to cool the reactor because the gas would have increased the radiation going up the stack. As a last resort, the reactor was flooded. But even this was ineffective for the first hour until all air to the furnace had been cut off.

The consequences: the area had to be evacuated; the prime minister was alerted; the reactor was ruined. Fortunately, there were no casualties, although radiation spewing over the countryside from the stack upped radioiodine concentration in local milk six times above that permissible.

While the reactor was being cemented up, a seven-man investigation team worked to produce a complete report. Just last summer the team completed its study on this, Britain's worst reactor accident, made some suggestions for instrumentation to assure future safety. Its recommendations:

- ▶For every reactor at least 100 thermocouples are needed for fuel temperature readings with a further 200 for a Wigner release. For graphite temperatures 300 more are required. Estimates put the total fitted to the Windscale reactor around 50.
- ▶Data processing and suitable display systems must give the operator an immediately visible picture of pile conditions.
- ▶Mechanical scanning system for burst cartridge detection must operate satisfactorily, particularly at high temperatures.
- ▶Increased instrumentation must cover blind spots in the pile, since falling temperatures recorded for one region of the pile misled the operating team to diverge the pile again. Subsequent work showed that normally coolest spots in the graphite became the hottest during Wigner release.

According to Sir William Cook (A. E. A.'s former engineering director) cost of modifications required for safety would have been \$1.5 million. Not all of this was instrumentation (improved filters in the stack were also required); it represents a small proportion of the reactor's estimated \$18 million cost.

—Derek Barlow

OHMITE® industry's most complete line of WIRE-WOUND RESISTORS

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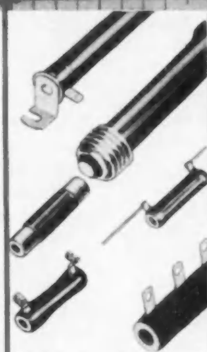
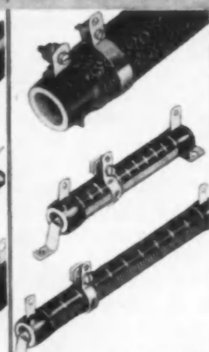
Ohmite has exactly the resistor you need

Ohmite offers the most complete line of high quality resistors on the market . . . fixed, adjustable, tapped, noninductive, and precision resistors in many sizes and types of terminals . . . in a wide range of wattages and resistances. All-welded construction. Ohmite application engineers will be pleased to help you in selecting the resistors for your job.



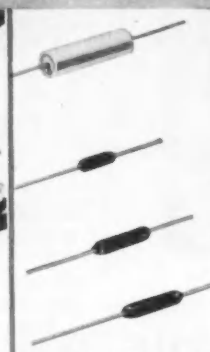
FIXED

Resistance wire is wound on a ceramic tube and protected by a vitreous-enamel coating. Many kinds of terminals available. May be single winding, tapped, or multisection. Watts, 3 to 1000; ohms, 0.1 to 1,700,000.



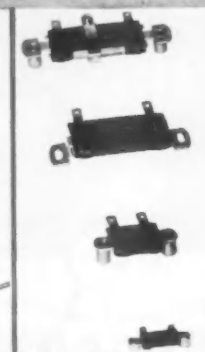
DIVIDOHM ADJUSTABLE

Vitreous-enameled resistors with the wire exposed in a strip along one side for contact with adjustable lugs. Most Ohmite resistors can be ordered adjustable. Watts, 10 to 1000; ohms, 1 to 100K.



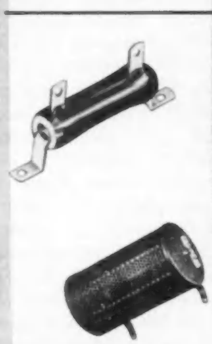
AXIAL LEAD

Small vitreous-enameled resistors with wire leads axially welded to caps on ends of the units. Also TUBEOHM ceramic jacketed style. Watts, vitreous 3 to 10; Tubeohm, 5 to 25; ohms, vitreous 1 to 50K; Tubeohm 1 to 25K.



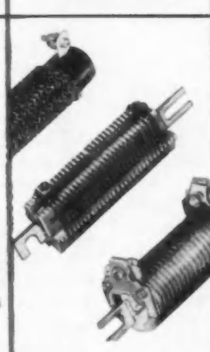
THIN

Resistance wire is wound on a core of flattened oval cross section and protected by vitreous enamel. Several sizes. Fixed, adjustable or tapped. Watts, 10 to 75; ohms, 0.1 to 100K.



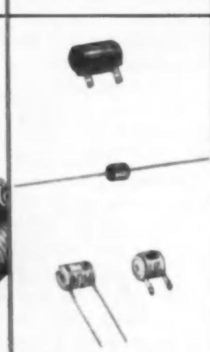
NONINDUCTIVE

Tubular vitreous-enameled resistors with special winding. Dummy antennas consist of assemblies of several resistors. Watts, 5 to 1000; ohms, 1 to 5000.



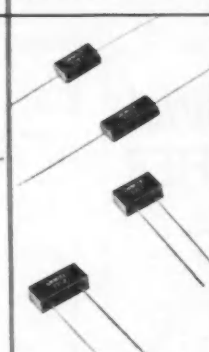
HIGH CURRENT

CORRIBS have exposed corrugated ribbon wound and enameled on a tubular core. POWR-RIBS have bare coil of edgewise wound ribbon or round wire.



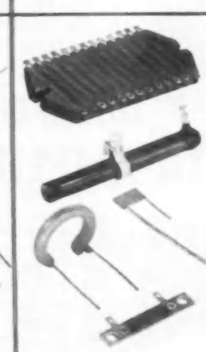
PRECISION WIRE-WOUND

Pie-wound resistors, encapsulated, impregnated, or hermetically sealed in glass. Also standard resistors wound to close tolerance. Watts, 1/8 to 2; ohms, 0.1 to 5 megohms.



PRECISION METAL FILM

Consists of a unique metal film permanently bonded to a glass plate. The assembly is sealed in a high-temperature resistant plastic case. Watts, 1/4 at 150°C to 1/2 at 105°C; ohms, 25 to 350K.



SPECIAL VARIETIES

Ohmite can provide toroids, flat strips, plaques, special-sized tubes, or tubes with mixed terminals, etc. Watt ratings and resistances are available as required.

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AROUND THE BUSINESS LOOP

New Dress for Askania

General Precision subsidiary acquires new name, higher status in move that also affects Kearfott, Link, Librascope.

Just a few days after General Precision Equipment Corp. had disclosed figures attesting to an unfortunate first six months in 1958, its subsidiary Askania Regulator Co. jumped into the plus side of the scales wearing a brand new dress and giving every indication that it would make great strides for itself and for its ailing parent in the months ahead.

Askania's new attire is multi-layered. On the surface is a name change, from Askania Regulator Co. to GPE Controls, Inc.; underneath is a revamped engineering and administrative network that will increase the subsidiary's products and services, and tie it securely to three other General Precision Equipment companies, Kearfott Co., Inc., Link Aviation, Inc., and Librascope, Inc.

Shand & Jurs, another General Precision subsidiary, will continue to serve the petroleum and pipe line industry. Compatibility of these products and those of GPE Controls is assured under the new program, said Edwin A. Link, president of General Precision.

• **Offices cross-staffed**—GPE Controls' executive office will remain in Chicago, at the old Askania address. In addition, it will have an eastern regional sales office in the Kearfott home office at Little Falls, N. Y., and a western office with Librascope, at Glendale, Calif. Headquarters for its national service organization will be in the Link home office at Binghamton, N. Y.

A glance at the names and affiliations of some of the principal officers of the new subsidiary brings into focus this implied cross-staffing, which makes GPE Controls probably the most versatile producer among the General Precision companies. These officers include: D. W. Smith, president of Kearfott, chairman; H. J. Velten, president, and C. L. Stancliff Jr., executive vice-president (both held the same offices in Askania); and W. E. Bratton, vice-president of Librascope, W. W. Wood Jr., vice president for manufacturing of Link, and C. H. Berry, assistant to the president of Kearfott, all vice-presidents.

The GPE Controls line will include the pneumatic, hydraulic, and electrohydraulic process control systems associated with Askania, plus these new items, all the result of the liaison with the other subsidiaries: analog and digital process control computers, data logging equipment, flow computers and integrators, analog-digital converters, and precision mechanical, electronic, and hydraulic components and subsystems.

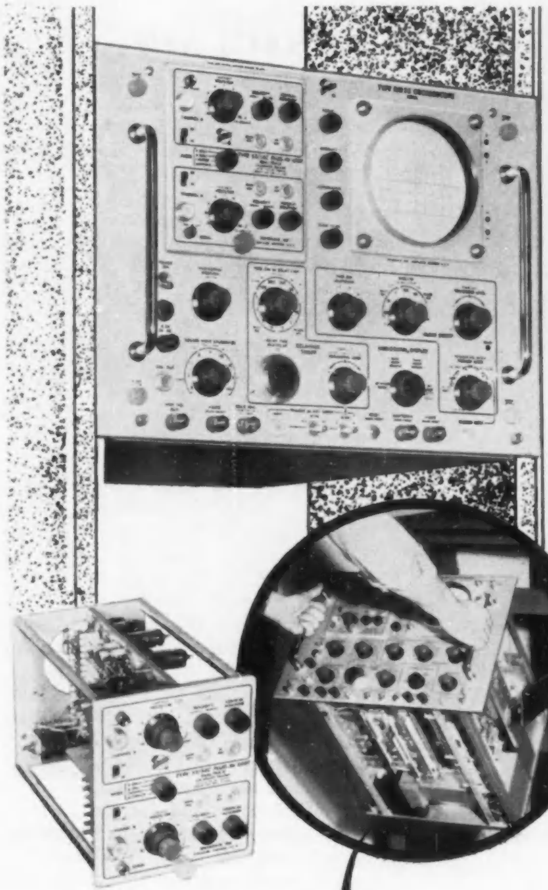
• **A versatile company**—This means, said Link, that "GPE Controls is in a position to design and install complete control-computer systems in virtually any industry—natural gas, chemical, petrochemical, both steel and nonferrous metals, metal fabrication, textile, paper, plastics, and printing."

General Precision's board of directors met Aug. 12 to approve the program. The next day came the interim report from Chairman Herman G. Place, which showed that: for the first six months of this year sales had dropped from \$93,299,000 for the same period in 1957 to \$85,568,000, and that consolidated net income had fallen from \$2,662,000 to \$754,000. In addition, no dividend on common stocks had been declared for the upcoming third quarter.

Place explained that second-quarter earnings were affected by a reappraisal of certain contracts for commercial jet simulators, a reappraisal that showed that the cost to General Precision of entering this new business would be higher than had been contemplated. As far as dividends were concerned, Place said first, that they had been paid on three preferred stocks, then that in view of an unsatisfactory earnings picture, it was decided to withhold payments on common stocks until an improvement could be observed.

Once a Subsidiary, Helipot Is Now a Beckman Division

Helipot Corp. is now more securely tucked under the Beckman wing. For a long time a wholly owned subsidiary of the big Fullerton, Calif., company, the 14-year-old Helipot is now functioning solely as a division. Transfer



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RACK-MOUNTING OSCILLOSCOPES FOR *Control Engineers*

These five new compact rack-mounting oscilloscopes offer the unmatched performance and versatility of their bench-type counterparts, having corresponding electrical characteristics. The cabinets of the rack-mounting models mount in a standard instrument rack, with chassis supported on slide-out tracks. Chassis can be pulled forward, tilted, and locked in any of seven positions for servicing convenience. All five have the same dimensions: 14" high, 19" wide, 22½" rack depth, 24" overall depth. All ten Type 53/54 Plug-In Units can be used in the vertical-deflection systems of these five new oscilloscopes.

Plug-In Units

TYPE 53/54K
Fast-Rise DC Unit.......... $125

TYPE 53/54L
Fast-Rise High-Gain Unit 185

TYPE 53/54C
Dual-Trace DC Unit 250

TYPE 53/54H
Wide-Band High Gain DC Unit 175

TYPE 53/54G
Wide-Band Differential DC Unit 175

TYPE 53/54D
High-Gain Differential DC Unit 145

TYPE 53/54E
Low-Level Differential AC Unit 165

TYPE 53/54B
Wide-Band High-Gain Unit ... 125

TYPE 53/54A
Wide-Band DC Unit......... 85

TYPE 53/54T
Time-Base Unit............ 225

TYPE 53/54R
Transistor Risetime Measurement Unit (to be available soon)

All prices f.o.b. Portland, Oregon

TYPE RM45
Electrically identical to Type 545

DC to 30 MC, 0.012-μsec risetime with fast-rise plug-in units.
0.02 μsec/cm to 5 sec/cm calibrated sweep rates.
Sweep Delay—calibrated, 1 μsec to 0.1 sec. (other delay ranges available on special order).
Signal Delay—0.2 μsec.
10-KV Accelerating Potential
Calibrator—0.2 mv to 100 v.
Electronically-Regulated Power Supplies
Price, without plug-in units........ $1550

TYPE RM35
Electrically identical to Type 535

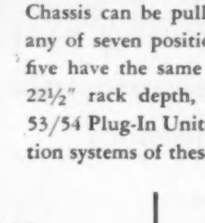
DC to 11 MC, 0.031-μsec risetime with fast-rise plug-in units.
0.02 μsec/cm to 5 sec/cm calibrated sweep rates.
Sweep Delay—calibrated, 1 μsec to 0.1 sec. (other delay ranges available on special order).
Signal Delay—0.25 μsec.
10-KV Accelerating Potential
Calibrator—0.2 mv to 100 v.
Electronically-Regulated Power Supplies
Price, without plug-in units $1400

TYPE RM41
Electrically identical to Type 541

The Type RM41 is also electrically the same as the Type RM45, except that it is without provision for sweep delay.
Price, without plug-in units........ $1245

TYPE RM31
Electrically identical to Type 531

The Type RM31 is also electrically the same as the Type RM35, except that it is without provision for sweep delay.
Price, without plug-in units...... $1095



Tilt forward-backward for easy access.

TYPE RM32
Electrically identical to Type 532

DC to 5 MC, 0.07-μsec risetime with wide-band plug-in units.
0.2 μsec/cm to 5 sec/cm calibrated sweep rates.
4-KV Accelerating Potential
Calibrator—0.2 mv to 100 v.
Electronically-Regulated Power Supplies
Price, without plug-in units......... $925

ENGINEERS—interested in furthering the advancement of the oscilloscope? We have openings for men with creative design ability. Please write Richard Ropiequet, Vice President, Engineering.

Tektronix, Inc.

P. O. Box 831 • Portland 7, Oregon
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CIRCLE 38 ON READER-SERVICE CARD

of operations to new facilities at Fullerton was to have been completed by the end of September.

Teachers Thrive on FIER-Case School

Ever since its formation nearly two years ago, the Foundation for Instrumentation Education & Research has been making itself indispensable to the field of control. A few weeks ago, with the report by Executive Director Lloyd Slater on the outcome of a course for post-high school technical-college teachers, FIER became eligible for an even greater degree of respect from the engineer.

As originally planned by FIER and Case Institute (CtE, April, p. 40), the course was to have run two weeks and accommodate 25 teacher-students. It actually ran nearly three weeks (July 7 to July 25) with an enrollment of 23. A battery of instructors, under Case's Irv Lefkowitz, hewed strictly to the line of dynamic analysis on a theoretical basis, and for the 23 students, many of whom had degrees dating back 20 years or more, the results were stimulating, clarifying, and satisfying.

• **Mostly "just right"**—Enrollees could really find fault with just one component of the course: the study sessions. Only five declared they were "very useful", while 14 said they were "of some value". On the other hand, though, only two said the sessions were "of little value". In all other respects, the course, held at Case, was an undisputed success. Students voted its scope, technical level and pace "just right", and the relation of its material to their work "very useful".

Said James P. Evans of Capital Radio Engineering Institute of Washington, D. C.: "This course has suggested to me the level I can teach at. I plan to use the lecture-demonstration approach to tie the subject to practicality. The math I'll use will include algebra, logs, vector analysis, some trig. Also I believe that I can teach my students to plot the control graphs used in the theoretical approach to control systems."

Specifically, the course:

• pointed up the tools of control systems analysis

• emphasized application of linear theory to the many slightly nonlinear systems found in actual practice

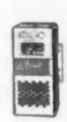
• showed how the analog computer

FIVE constant voltage transformer types answer most stabilizing needs

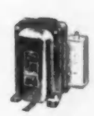
1 **The Harmonic-Free Constant Voltage Transformer** gives you all the advantages of static-magnetic voltage regulation *plus* "sine-wave" output. Remington-Rand, for example, uses this 9 kva transformer to provide continuous, completely-automatic voltage regulation to their Univac model 60 and 120 computers. The Sola regulator is shown above at the left with the front panel of the cabinet removed. It is a custom-built unit.

Sola harmonic-free regulators deliver ±1% regulation with ±15% line voltage variation. The output wave has less than 3% total rms harmonics. Available from stock in seven sizes ranging from 60 va to 3kva; custom designs manufactured to your specifications in production quantities.

2 **Standard***: Constant Voltage Transformers for electrical and electronic equipment . . . regulation ±1% . . . response within 1.5 cycles . . . no tubes, moving parts or manual adjustments . . . static-magnetic regulation ...limits current on load faults.

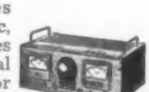


3 **Plate-Filament***: Regulation is ±3% with line input between 100-130v . . . plate and filament windings are combined on a single, compact core for chassis mounting . . . good isolation of input and output circuits . . . automatic, static-magnetic regulation.



4 **Filament***: Regulation ±1% with input voltage fluctuations up to ±15% . . . 6.3v output for large numbers of electron tubes . . . current-limiting action minimizes cold inrush currents, also protects against damage from load faults... 75-80% efficiency.

5 **Adjustable, Harmonic-Free**: Provides output adjustable from 0-130 volts ac, also fixed 115 volts ac . . . regulates within ±1% with less than 3% total rms harmonic content . . . portable for lab or shop bench use, or mounts on 19" relay rack.

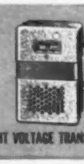


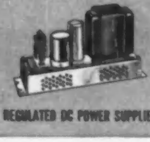
*Available from stock or custom-designed.

For complete data write for Bulletin 26J-CV-170

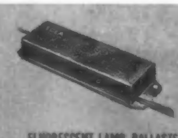
Sola Electric Co., 4633 W. 16th St., Chicago 50, Ill., BIshop 2-1414 • Offices in Principal cities • In Canada, Sola Electric (Canada) Ltd., 24 Canmotor Ave., Toronto 14, Ont.

SOLA


CONSTANT VOLTAGE TRANSFORMERS


REGULATED DC POWER SUPPLIES


MERCURY LAMP TRANSFORMERS


FLUORESCENT LAMP BALLASTS

can be used to analyze systems with nonlinearities

- explored the techniques and possibilities of the frequency-response method of analysis

Most of the teachers agreed that to be ready for a technology like instrumentation, the post-high-school student must have more basic mathematics and science than is available to him today; and that if he is to function properly as an engineering aide, he should be exposed to a heavy dose of theory.

Philco, Leeds & Northrup Launch a Computer Project

Philco Corp. and Leeds & Northrup Co. have joined hands—and budgets—to produce a digital computer expressly designed for the process control field. "The computer which results from this project," said Presidents James M. Skinner Jr. of Philco and I. Melville Stein of L&N in a joint statement, "is expected to be unusually flexible and broad in application, as well as outstanding for its reliability. Through its nationwide marketing and service organization, Leeds & Northrup plans to utilize the unit as an integral part of L&N industrial control systems of advanced scope.

"Such computer-control systems should enable operators of chemical plants, petroleum refineries, electric power plants, atomic energy processes, steel mills, and metalworking plants to take a significant step toward optimizing the economical operation of processes and the raising of product quality."

Engineering Wins "College" Status at U. of Rochester

The University of Rochester (N. Y.) has assigned its long-established departments of chemical and mechanical engineering and a brand new Dept. of Electrical Engineering, to an equally new College of Engineering. In each department are four-year courses leading to a BS degree.

Lewis D. Conta, professor of mechanical engineering and chairman of the old Div. of Engineering since 1950, has been named acting dean of the college, and Daniel W. Healy Jr., who comes from the engineering faculty of Syracuse University, has been named professor of electrical engineering and chairman of the new department.

In digital-computer-system design

How to save $100,000 worth of computer time

Look for the biggest gain where you normally lose the most. Applying this bit of external logic to the digital computer, you will find a big advantage for yourself (and your customers) in a tape handler that runs for months with only routine care. This pre-production Ampex FR-300, stripped down to its underwear, was photographed undergoing an accelerated endurance test. It proved out the basic design features that have made this possible.

AMPEX MEETS THE CHALLENGE OF THE MOVING PART

Within the computer's own circuitry, nothing moves but electrical currents. But the tape handler must keep pace with mechanical movements of incredible speed. A tape can't be moved by electrons alone!

On the Ampex FR-300 Tape Handler, the magnetic tape goes from zero to 150 inches per second in just 1.5 milliseconds – an acceleration of 260g. A flip-flop pinch-roller mechanism makes contact between tape and driving capstan. It has an inertia brake that stops the tape with equal deceleration. This mechanism is the single most critical part in the tape handler. Ampex engineers tested prototype designs through as many as 50,000,000 start-stop cycles. This equals one year of extra-heavy-duty service for the most critically stressed part in the entire tape handler. Replacement at recommended intervals virtually eliminates unpredicted shutdowns from this cause of failure.

Yearly Value of Reduced Maintenance Shutdown

	Hourly computer rental (or amortization)		
Hours saved per week	$ 100	$ 200	$ 300
1	$ 5,200	$ 10,400	$ 15,600
2	$ 10,400	$ 20,800	$ 31,200
5	$26,000	$ 52,000	$ 78,000
10	$52,000	$104,000	$156,000

On other parts of the Ampex tape handler, we alternate between the philosophies of the instrument maker and the tractor builder. Anything that accelerates with the tape is incredibly light. For instance, tape tensioning is done by columns of air. On the other hand, the motors, bearings and frame are as rugged as a bulldozer.

DEPENDABILITY, OF COURSE, BUT SPEED IS MOST IMPORTANT OF ALL

Ampex's non-stop dependability would be meaningless if it were achieved at any sacrifice in input/output transfer rate. It isn't. The FR-300 offers the fastest digital-transfer rates available today – 30,000 to 90,000 six-bit characters per second. It has the shortest inter-record distances – ½ inch with ample safety factor. And it compacts the most data per file with its 300 bit-per-inch packing density.

We suggest you take the earliest opportunity to watch an Ampex Digital Tape System in operation. We are sure it will win your confidence – just as it has sold itself to a number of major computer manufacturers. In the meantime may we send you literature? Write Dept. **HH-18.**

AMPEX INSTRUMENTATION DIVISION • 860 CHARTER STREET • REDWOOD CITY, CALIFORNIA

Phone your Ampex digital tape specialist for personal attention to your needs. District offices serve the U. S. A. and Canada. Foreign representatives cover the free world.

IMPORTANT MOVES BY KEY PEOPLE

Erickson, Long-Time Daystrom Man, Moves to Beckman

Robert Erickson, the new operating executive of Beckman Instruments, Inc., is functioning under the official title of executive vice-president. He joins the Beckman organization after a long-time association with Daystrom, Inc., most recently as president and director of the subsidiary Heath Co. He has also been vice-president of Daystrom itself, operating vice-president of the Instruments Div., and a board member of several other subsidiary companies. Before connecting with Daystrom, Erickson was general plant manager of RCA's Home Instruments Div.

General Doolittle to Steer Space Technology Board

Keynoting the move by Ramo-Wooldridge's Space Technology Laboratories toward completely separate status physically as well as organizationally is the appointment of Gen. James H. Doolittle to chairman of the STL board of directors. Doolittle will continue as chairman of NACA, the Air Force Scientific Advisory Board, and Shell Oil Co., but will retire as vice-president of Shell when he takes on his new duties at STL the first of the year.

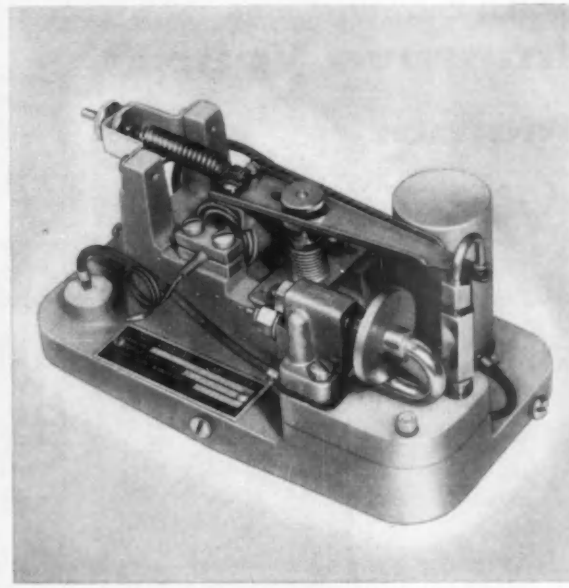
Also at that time, Louis Dunn, now executive vice-president and general manager of STL, will become president, and Simon Ramo, presently serving as president, will take a position on the board of directors.

STL, with overall scientific responsibility for the Thor, Atlas, Titan, and Minuteman missiles, is said to represent the largest concentration of scientists and engineers in the nation devoted exclusively to the ballistic missile and to space problems.

CEC Appoints Chiefs of Chemistry, Physics Research

Charles F. Robinson, physicist, and Leland G. Cole, chemist, have been named chief researchers in their specialties by Consolidated Electrodynamics Corp. Robinson joined CEC in 1947 as a staff physicist and became senior physicist in 1952. Cole, for-

LOW COST AND EASE OF INSTALLATION PERMIT WIDE USAGE.



OPERATIONAL SIMPLICITY IN A RUGGED, COMPACT UNIT.

TAYLOR ANNOUNCES NEW LOW-COST TEMPERATURE TRANSMISSION

New SENSAIRE* Transmitter: rugged, compact, force-balance, with mercury-filled system. Self-compensating for ambient temperatures.

The new Taylor SENSAIRE temperature transmitter now makes more widely available low cost temperature measurement within limits of minus 30°F. to plus 1200°F., with simplified adjustments and excellent repeatability. Available in range spans of 50°F., 100°F., 200°F., and 400°F.

Individual transmitters are factory calibrated in one of four available range spans. A simple thumb-screw adjustment zero-sets the instrument within wide limits. This adjustment is accomplished with high accuracy, and no further calibration is necessary. Factory calibrated accuracy is well within 1% of rated range, below 550°F; 1½% above 550°F.

All SENSAIRE transmitters and components are interchangeable (regardless of range). A measuring system encompassing a new range span or new range limits (other than those obtainable with zero adjustment) may be added in the field.

Write for SENSAIRE **Bulletin 98293,** Taylor Instrument Companies, Rochester 1, N.Y., or Toronto, Ontario.

*Trade-Mark

Taylor Instruments

MEAN ACCURACY FIRST

Unusually Fast Response. Due in part to its extremely small bulb, the SENSAIRE transmitter has an unusually fast speed of response. However, for processes that require it, the SPEED-ACT* (derivative response adjustment) unit is available. The SPEED-ACT feature is of special value where the bulb is placed in a well, or in processes using material with poor thermal transmission rates.

Easy to Install. Mounts in any position. Universal bracket provides for direct mounting on pipe, wall, or wrench head of well or separable bushing. Small and extremely compact, the SENSAIRE transmitter measures only 7¾" x 4¾" x 4½"; weighs only 7 lbs.

CIRCLE 44 ON READER-SERVICE CARD

merly director of the Dynamics Laboratory of Robertshaw-Fulton Controls Co., joined in 1955 as senior chemist. Both men are prolific inventors and authors in their fields.

Jeffries to Represent ISA in NRC's Engineering Div.

Robert J. Jeffries, president of Data-Control Systems, Inc., and president of ISA, has been appointed to the National Research Council to represent the ISA in the NRC's Div. of Engineering.

Other Important Moves

With the appointment of **Louis A. Turner** as deputy director, Argonne National Laboratory fills a vacancy that has been standing since **Norman Hilberry's** elevation from deputy director to director in 1957 (CtE, May '57, p. 188). Turner, formerly director of the laboratory's Physics Div., holds the Presidential Certificate of Merit for his wartime work in electronics. Before joining the laboratory, he was head of the Dept. of Physics and professor of physics at the State University of Iowa.

John B. Olson, named chief engineer of Computer Measurements Corp., is the former manager of engineering services of the Berkeley Div. of Beckman Instruments, Inc.

The new chief engineer of Electro Mechanical Specialities Co., Inc., of Los Angeles is **Ray Rhodes** who comes from Electronic Specialty Co., where he held the same position.

Obituaries

Milton Abramowitz, 43, head of the Computation Laboratory of the National Bureau of Standards' Applied Mathematics Div.; of a heart attack.

William F. Durand, 99, aviation pioneer and a past president of ASME.

Melvin H. Emrick, 47, president and chairman of the board of Ettco Tool & Machine Co., Inc., of Brooklyn; of a heart attack.

Manoel F. de Mayo Behar, 69, vice-president of Instruments Publishing Co. and editor emeritus of *Instruments and Automation.*

Allison C. Neff, president of the National Society of Professional Engineers in 1955-56; of a heart attack at his home in Middletown, Ohio. He was vice-president of Armco Drainage & Metal Products, Inc.

OPERATION up turn Buy now for extra values GENERAL ELECTRIC

COMPUTER PROGRESS

Digital and Analog Computers at Work

ARTICLE 2 VOLUME 1

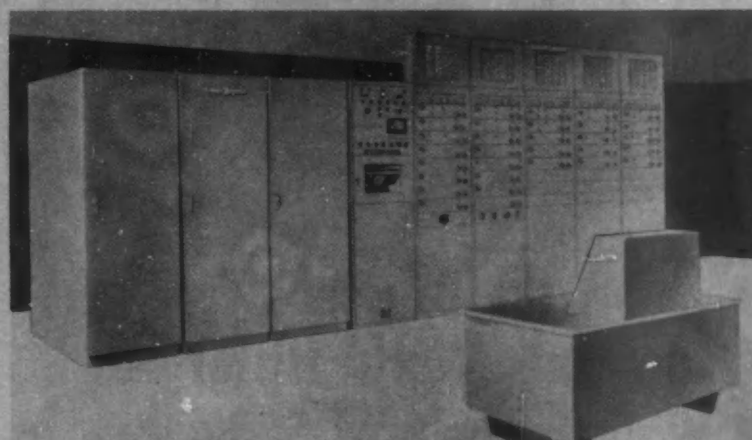
NEW ELECTRONIC HEAT RATE COMPUTER HELPS SLICE THROUGH AIRCRAFT "HEAT WALL"

This latest General Electric Computer helps simulate aerodynamic heating encountered in flight by high speed aircraft. Compression of air around an airframe increases air temperature. The temperature rise can be calculated from wind tunnel test data taken from scale models. Stresses created by artificially heating actual airframe sections in a high temperature test laboratory are then analyzed to aid in structure design. The Heat Rate Computer not only *calculates* the amount of electrical energy required by banks of infra-red lamps or other heat sources, but also *controls* the energy flow.

Calculation of the heat flow necessary for accurate simulation can be made by satisfying the thermal equilibrium equation:

$$Q = A\ [h(T_{aw} - T_s) - BT_s^4]$$

where: Q = heat rate (BTU/hr)
A = area (sq. ft.)
h = heat transfer coefficient (BTU/hr., sq. ft., °R)
T_{aw} = adiabatic wall temperature (°R)
T_s = surface temperature of structure (°R)
B = radiation factor (BTU/hr., sq. ft., °R⁴)



The Heat Rate Computer solves this equation instantaneously using both digital and analog techniques, then sends energy to the heat source at the proper heat rate, Q. Transducers mounted on the airframe provide the feedback signal proportional to T_s.

One large computing system has been designed by General Electric to calculate and control the heat flow to 39 airfoil areas. The unique use of a magnetic drum to digitally store T_{aw} and h curves insures freedom from drift and permits easy storage of, and rapid access to curve data. Multiplexing and time-sharing minimize the amount of electronic circuitry.

COMPUTER DEPARTMENT LAUNCHES OPERATION UPTURN WITH NEW MILLION-DOLLAR PLANT IN PHOENIX, ARIZONA

General Manager H. R. Oldfield, Jr., is pictured at the controls of the Operation Upturn steam shovel which recently broke ground for the new 104,000 square foot permanent plant which is expected to be completed by December of 1958.

"Our business is good and getting better," Oldfield said. "We're going to continue to expand during the year, adding perhaps a hundred or more people." The department now has over 800 employees.

The 160 acre site is located in Deer Valley Park, northwest of Phoenix along the west side of the Black Canyon Highway and south of the intersection with Thunderbird Road.

COMPUTING SERVICES GROUP HANDLES COMPLEX ORIGIN-DESTINATION STUDY FOR WESTERN CITY

The Computing Services Center of the G-E Computer Department recently completed an origin-destination tabulation for the Phoenix-Maricopa County Traffic Study Group in Phoenix, Arizona. The results of this tabulation, when analyzed, will enable the group to plan the street and highway development program of this desert metropolis for years to come.

The original survey information was obtained by the city-county personnel using the interviewing procedures set up by the U. S. Bureau of Public Roads. The data was put on punched cards and then turned over to G-E for processing and tabulation.

Using manual, or simple computing methods, such tabulations often take many months—sometimes years—to complete. However, using the Computing Services Center Computer on a rental basis, the job was completed in just a few weeks. The Computer Department also performed the difficult programming job.

(Programming, simply stated, is the translation of the solution method into the language a computer can understand, and the issuance of instructions to the computer so that it will process the information it is fed.)

The Computing Services Center of G-E's Computer Department is staffed with 125 analysts, programmers, coders —all leaders in the computer field. Their services are available, along with time on the large and versatile type 704 computer, to handle the problems of industry, business, government and education.

For more information contact your nearest Apparatus Sales Office, or Computer Department – Room 101, General Electric Company, 1103 North Central Avenue, Phoenix, Arizona.

CPA–7

Progress Is Our Most Important Product

GENERAL ELECTRIC

At the Brussel's Fair IBM's Ramac presents World History in 10 languages with the help of Skinner Solenoid Valves

Visitors to the World's Fair at Brussels are given the opportunity to submit history questions to IBM's Ramac and get their answers in any one of ten languages. Millions have been fascinated by this amazing electronic data processing machine.

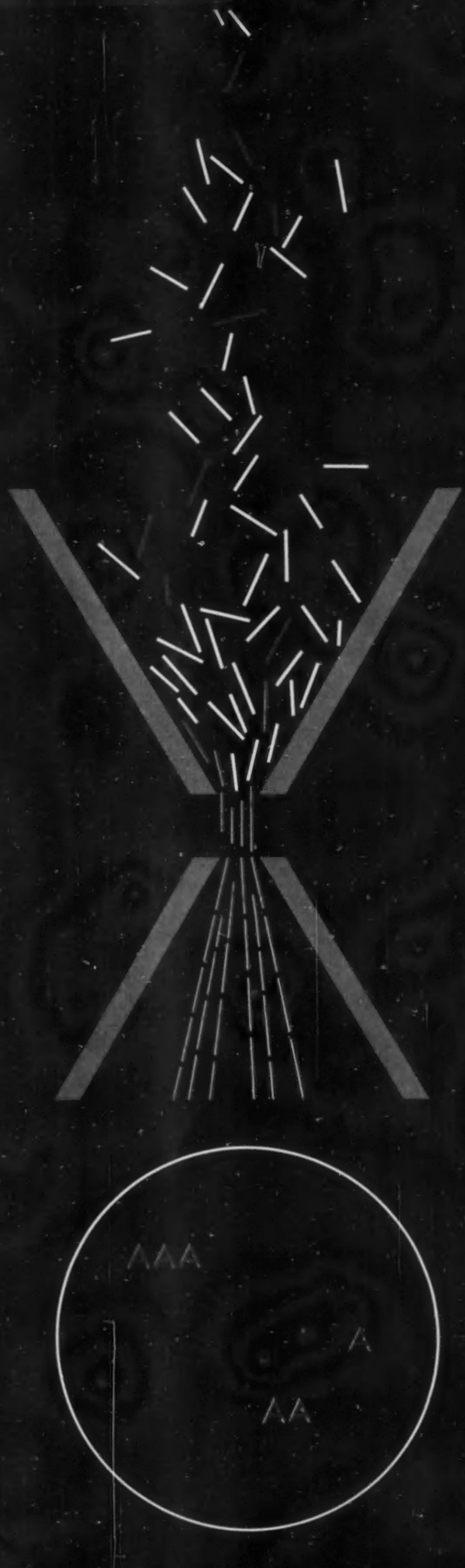
Ramac is a vast library of facts. By means of 50 rotating metal disks 5,000,000 alphamerical characters can be stored and selected at the touch of a button. The Ramac can punch 100 cards a minute, transfer data from punch cards to disks at a rate of 125 cards per minute, and print reports at speeds up to 80 lines per minute.

Three Skinner V5 three-way valves are used in the access control mechanism. One valve engages the access arm at the exact location of the disk, while the second valve disengages the arm after the read-write sequence has been completed. The third valve positions the read-write head at the precise location on the proper disk tract.

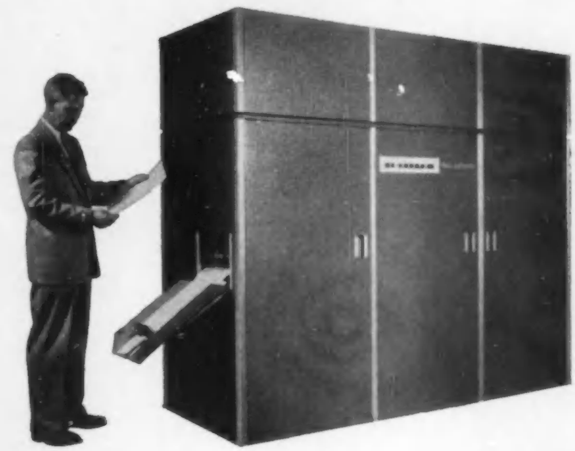
Skinner has a wide selection of solenoid valves for all types of applications. If you have a control problem, why not take it to a Skinner engineer or representative. You will find Skinner representatives listed in the Yellow Pages or write direct to Department 340.

SKINNER ELECTRIC VALVE DIVISION NEW BRITAIN CONNECTICUT
105 EDGEWOOD AVENUE
THE CREST OF QUALITY

 CIRCLE 47 ON READER-SERVICE CARD CIRCLE 48 ON READER-SERVICE CARD →



leaders in readout and display . . .



S-C 5000

World's Fastest Electronic Printer

Printing computer data five to ten times faster than the fastest electro-mechanical printers, the S-C 5000 High-Speed Electronic Printer has broad applications throughout business, government, and industry . . . wherever high-speed data processing systems are used . . . wherever a more efficient and economical method of high-speed printout is desired. Establishing new standards of *performance, reliability,* and *versatility* in the field of hard copy printing, the S-C 5000 is an outstanding example of Stromberg-Carlson leadership in the development and manufacture of readout and display equipment. Write today for further information.

Prints 100,000 Words per Minute

Eliminates Troublesome, Fast-Moving Mechanical Parts

Capable of Registered Printing on Pre-Printed Forms

Prints Without Impact on Untreated Paper of All Types

Reduces Cost of High-Speed Data Processing

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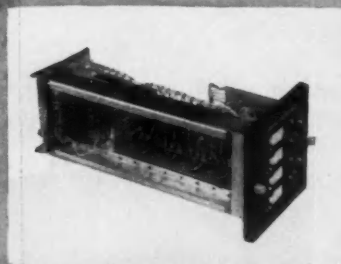
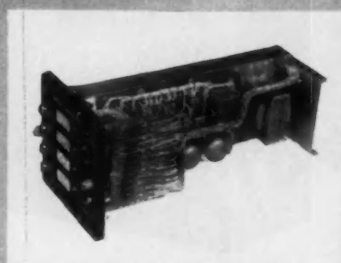
"There is nothing finer than a Stromberg-Carlson"

Developers and Manufacturers of S-C 1000 Direct Viewing Displays • S-C 2000 Bright Displays • S-C 3000 High Speed Communications Printers • S-C 4000 High-Speed Microfilm Printers • S-C 5000 High-Speed Electronic Printers



PRINTED CIRCUITRY INCREASES RELIABILITY AND FLEXIBILITY.



USE OF THE HIGHEST QUALITY COMPONENTS INCREASES RELIABILITY . . . ASSURING MAINTENANCE-FREE OPERATION.

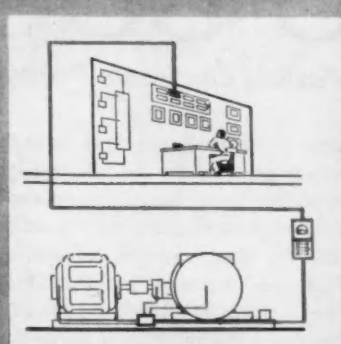
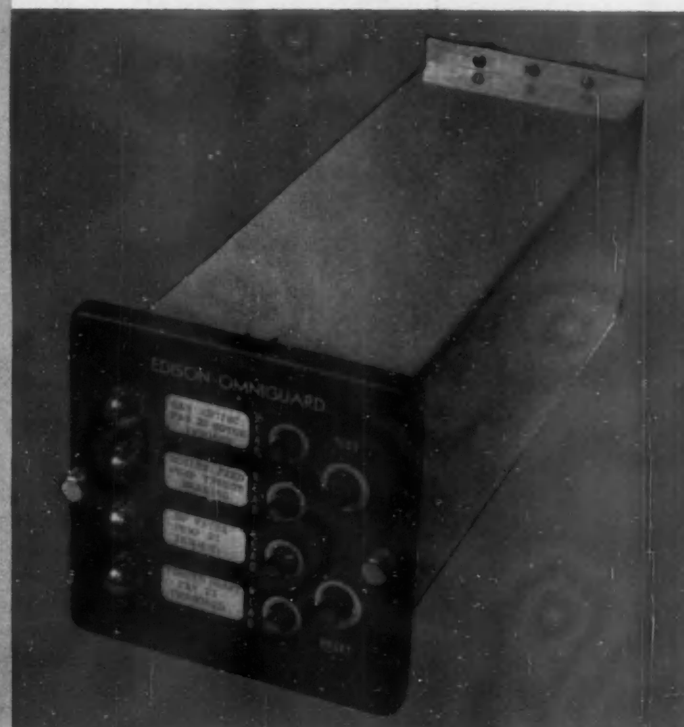


DIAGRAM SHOWS TYPICAL OMNIGUARD SYSTEMS.

THOMAS A.

EDISON

New printed circuit model 310 omniguard temperature monitor



New Versatility . . . and *proven reliability* in temperature detection is made available with the introduction of the new Model 310. Printed circuit design and quality components guarantee a minimum of maintenance for the life of the unit.

Now, you have a temperature monitoring system incorporating all the flexibility, simplicity, quality and economy instrument and systems engineers have needed. The Edison Model 310 is a *mass produced* system whose modular construction makes it possible to have *custom-tailored* installation. Other important features of the new Omniguard Model 310:

- Design keeps pace with growing instrumentation.
- Eliminates corrective maintenance and downtime.
- Complete Unit plugs in.
- Designed for more than a million operations.

Call or write for more complete information.

Thomas A. Edison Industries

INSTRUMENT DIVISION

38 LAKESIDE AVENUE, WEST ORANGE, N. J.

EDISON FACTORY OFFICES ARE LOCATED IN: EVANSTON, ILLINOIS; DALLAS, TEXAS; DAYTON, OHIO; SHERMAN OAKS, CALIFORNIA.

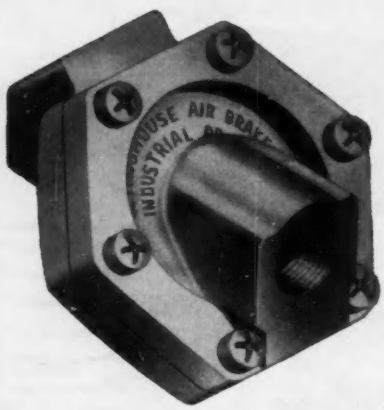
 CIRCLE 49 ON READER-SERVICE CARD

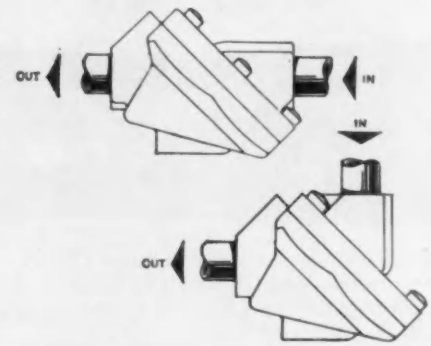
New Product Announcement

WESTINGHOUSE QUICK RELEASE VALVE

light weight...flexible mounting...more sensitive control

Here is the new Westinghouse Quick Release Valve. Its all-new design features a number of improvements which make it the most efficient device you can use to vent air-pressure cylinders and other pneumatic equipment.





Only 7 ounces!—The Westinghouse Quick Release Valve is made of aluminum—it weighs only seven ounces. It is ideally suited to meet installation requirements where weight is an important factor.

No bracket needed—A key feature of this valve lies in the flexible mounting of its supply port, allowing the inlet and outlet ports to be assembled on the same center line or at right angles to each other. In addition, you need no bracket to install the new Westinghouse Quick Release Valve.

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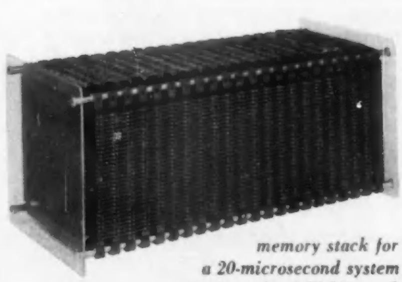

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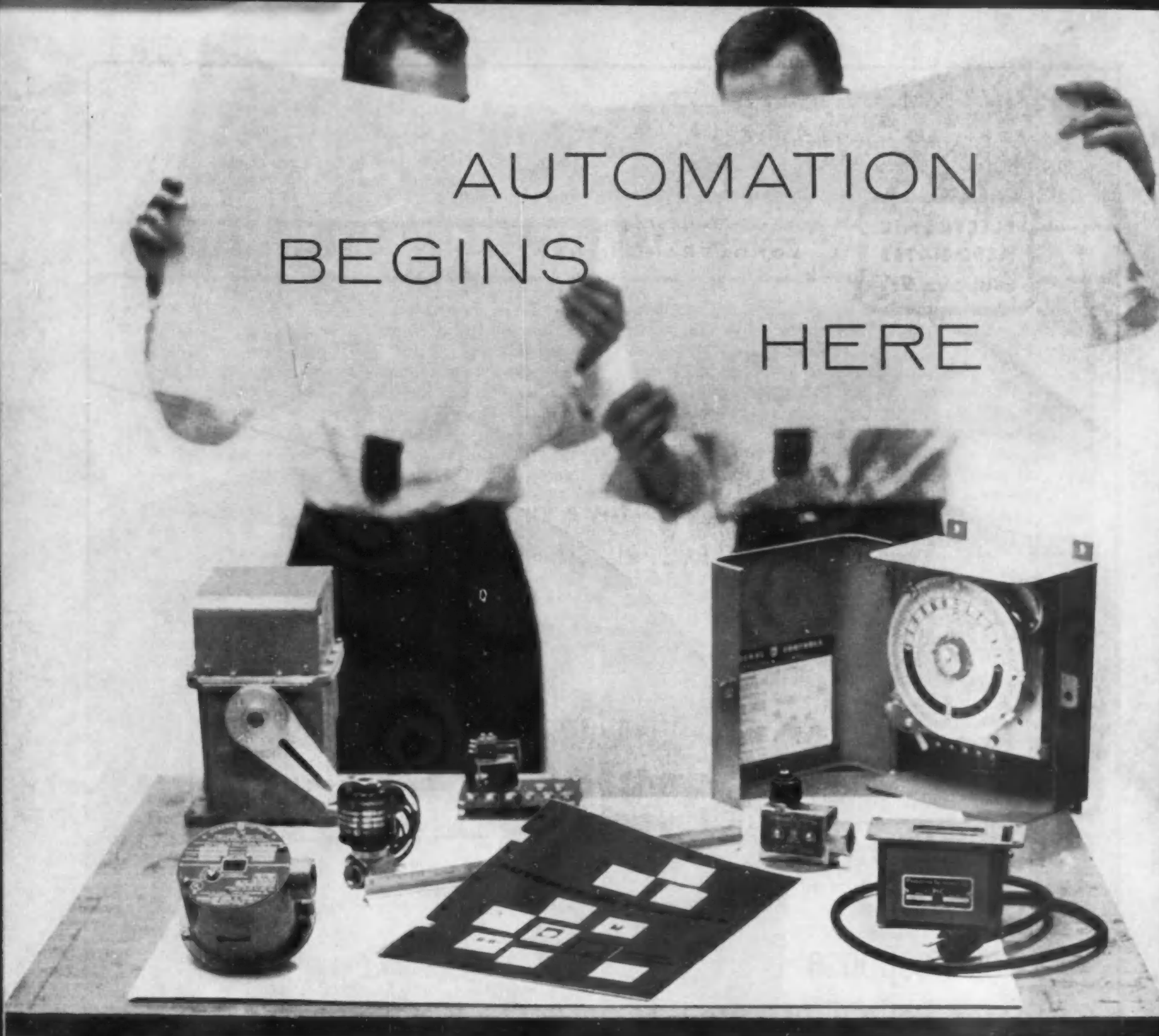

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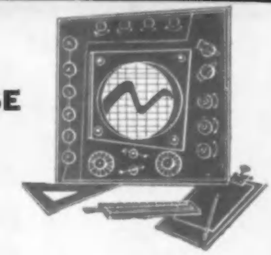

Estimating instrument sales

U.S. Department of Commerce analysts are studying a new high accuracy technique for estimating instrument industry sales, one relying on statistical mathematics instead of trend projection. The project is the brainchild of Louis A. Edelman, analyst in the Scientific, Motion Picture & Photographic Products Div., headed by Nathan D. Golden.

Rather than merely extrapolating instrument sales figures—a common technique for predicting future sales—Edelman applies a multiple correlation, statistically relating what he feels are four key variables in instrument sales. The four: 1) total *weighted* capital expenditures planned for plant and equipment, 2) instrument sales (from census data, using SIC groups which contain a number of significant instrument categories, though some of them are not nominally identified as instrument classes), 3) budgeted military expenditures for aircraft and missiles, and 4) budgeted government expenditures for additions to research and development plant.

The first thing Edelman did was to determine how to weight industrial capital expenditures (sums spent for major installations of building and equipment). He felt weighting was necessary because of each dollar spent for capital expenditures, the chemical industry, for example, puts a bigger proportion into instrumentation than the utility industry. To determine weighting factors, Edelman performed a partial correlation analysis on sales figures collected since 1945. He divided them into five groups with these results:

	Weighting Figure	Average Percent of Capital Expenditures
Chemical	4	4.0%
Petroleum	2.5	9.5
Public Utilities	1	15.0
All Other Mfg.	1	24.5
All Other Non-Mfg.	Excluded	47.0

Edelman found that he could exclude expenditures by nonmanufacturing installations because their investments in instrumentation were so small.

Edelman's use of "additions to R&D plant" as a key instrument sales indicator represents another new view. Sales people have watched the growth of R&D expenditures with enthusiasm because they felt sure that this meant more instrument sales. But it's been difficult to figure how much. That's because the bulk of R&D funds (as high as 75 percent) go into labor and overhead expenses—not instrument sales. Additions to R&D plant, reasons Edelman, is more directly proportional to instrument sales.

This new analysis of instrument sales has turned up some other interesting information. For example, a survey conducted by Golden's group showed that instrument expenditures as a percent of capital expenditures varied considerably: in chemical, 1-15 percent (depending on whether the plant employs a dry or wet process; dry processes need much less instrumentation); in petroleum, 2.5 to 12 percent, and in public utilities, 1 to 3 percent.

It's also possible, says Edelman, to deduce mathematically a lag time between plant construction awards and instrument sales. Based on a preliminary study, Edelman estimates that it is 6 to 9 months. There's also a similar lag in military expenditures for aircraft and missiles. Edelman plans to determine in the future just how much time elapses between passage of military appropriations for a missile and the sale of instrumentation for that missile.

One important and valuable feature of this technique is that it uses anticipatory data to predict sales. The predicting variables are available well in advance of the period for which the sales estimate is planned.

After carrying out his prognostications of instrument industry sales, Edelman plotted the trend of sales since 1946. Using the equation

$$\frac{s}{s_o} = e^{kt}$$

where s_o = dollar sales in base year prices at an initial yea
s = sales in any year.

he calculated the rate of growth constant k as 0.1089, a figure strikingly close to the $k = 0.1142$ calculated by General Electric analyst H. C. Dickinson in 1956 (CtE, July '56, p. 16). This verifies the industry's fantastic growth rate: a tripling in sales every 10 years.

Using his new technique for correlation, Edelman took a look at sales as the recession apparently ended. He predicts that sales in the last half of 1958 will total about the same as those in the last six months of 1957. His half year estimate: $1.50 billion.

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Control
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OCTOBER 1958

More Information per Dollar

We note the phrase "more data per dollar" occurring more and more often in the technical press, and now even as the theme of an international engineering conference. As a catch phrase it is fine. We take issue with it, however, for the sake of accuracy of terms and engineering good-sense. "More *used* data per dollar" is what we need.

The same technical press which so glibly errs in this misuse of words has for years exhorted engineers to keep their designs economically sound, for only the economical designs can survive industrial usage. The industrial commandment to design economically applies just as strongly to control system designs, as many of us know so well.

In general, to be economical a controller must work with information about the controlled process, converting it to power only at the control actuator. A control system is thus seen to be an information handling and processing system, and the control engineer a designer of information handling and processing systems. A simple servo is not given input data accurate to six places if it is sensitive only to three, nor is a sampling system supplied data 1,000 times per sec if it can respond only 10 times per sec. So with larger systems. Data should not be collected only to be recorded and never used. And even if collected by the excess capability of an otherwise inexpensive primary sensor, it certainly should not be processed to some more easily used form unless it is truly used in the development of a final control signal. "More data" may not be needed, even though equipment is available which can supply it. It isn't cheap if it isn't needed.

Data collected is data. Data recorded is data. Data processed is data. Data *used* for control is information. Data not used is waste and waste is uneconomical. As a design rule, gather data you can really use. "More bits per dollar" and "more data per dollar" are catch phrases with big holes in their logic. More *used* data per dollar is the realistic approach to economically sound control systems.

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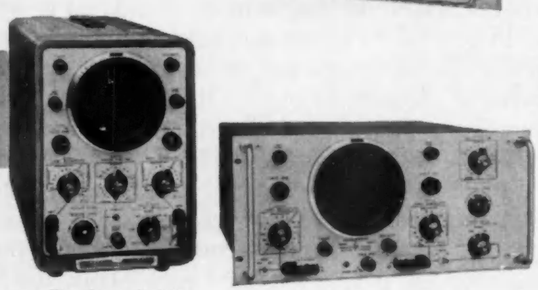

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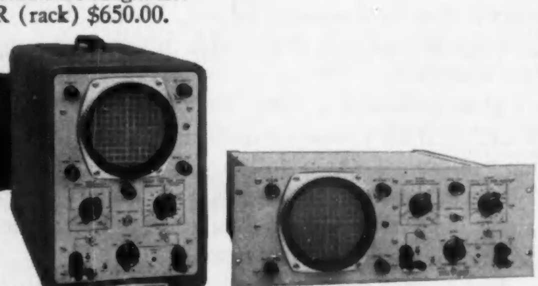

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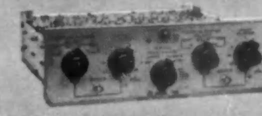

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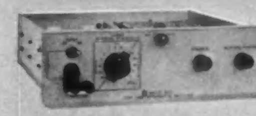

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Nonlinear Systems Design

PART I: HOW TO CONSTRUCT A PHASE PLANE PLOT

JOHN E. GIBSON, Dept. of Electrical Engineering, Purdue University

THE GIST: Equipped with standard design techniques for handling idealized *linear* systems, today's control engineer faces the more realistic and far more difficult problem of finding similar standards for designing *nonlinear* systems.

One approach to this problem involves the construction, interpretation, and application of a phase plane plot. Although described in a number of places, the phase plane approach has not been widely adopted by system designers. Here, and in two subsequent articles, the author demonstrates its practical application to typical design problems. This first article provides two step-by-step procedures for constructing the phase plane plot.

No single set of rules exists for the analysis and design of all nonlinear control systems. Still, most nonlinear systems tend to fall into definite classes, and design techniques applied to a given class can be standardized to some degree. To-date, only a few such classes have been studied, but as time goes on the list will surely broaden.

When the nonlinearity of a system is not extreme, the engineer often ignores it as a first approximation or assumes linearity about an operating point. Or he might use linear techniques to design the system for the two extremes of the nonlinearity, and hope for satisfactory operation in between. But when nonlinearity is a major factor in system response, quasilinear methods fail completely; an investigation of system stability requires solution of the nonlinear equations. This series describes one generally accepted method for solving these equations, the phase plane approach.

A graphical analysis in the phase plane itself, or a numerical analysis of the successive difference type may be used. In the event the latter is chosen, the phase plane still provides a convenient display for interpreting results. The phase plane plot of a nonlinear system is analogous in a sense to the root locus diagram of a linear system, in that it displays system characteristics over an entire operating range.

The phase plane is a plot of the variable under consideration vs. its time derivative. From the general shape of the plotted curves, it is possible to determine system characteristics. Although time is implicit on the plot, it is not the independent variable. A phase plane plot of a closed-loop system usually shows error vs. the time rate of change of error, with error plotted along the horizontal axis.

Generally, the phase plane analysis is limited to second-order systems. Since higher-order derivatives cannot be plotted on the phase plane, higher-order systems would not be completely defined. Of course, the method might be extended from phase planes to phase spaces of n dimensions to handle nth order systems, but then it loses some of its simplicity and convenience.

Barring analytic solution and the use of a computer, the phase portrait is obtained in one of three ways:

- Numeric solution. This method uses the phase plane merely as a score card for interpreting results of the solution.
- The isocline method. Here the system equation is not solved. Instead, the loci of constant slopes on the phase plane are found and this permits sketching of the phase trajectory.
- Graphical construction methods. One example is the delta method described later.

This article deals with construction of the phase plane plot by both the isocline and graphical methods. Part II will interpret the diagrams.

Design of controllers for nonlinear systems, still a

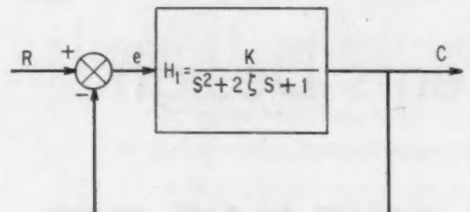


FIG. 1. Block diagram of a second-order, unity ratio servo.

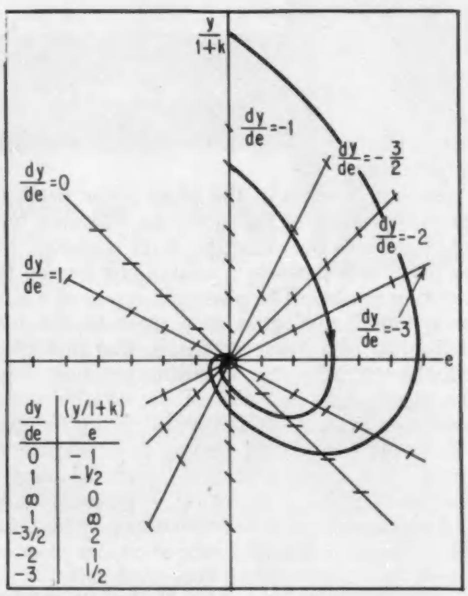


FIG. 2. Phase plane plot of a simple quadratic system, using the isocline method.

difficult task, has been eased somewhat by certain phase plane techniques. The problem of optimum switching moment in a relay servo, discussed by Stout (Ref. 1) in 1956, is an example. This applies also to higher-order systems where, in certain cases, the theoretical trajectory for an ideal system can be plotted on the phase plane, and an actual system optimized by comparison to this plot. Part III will introduce the philosophy of controller design.

Isocline method

The isocline method requires manipulation of the system equation to obtain the loci of constant slope. Once these loci have been plotted, it is possible, with given initial conditions, to sketch the phase plane trajectory without actually solving the system equation. As an example, consider the linear second-order system in Figure 1. The equation represents the standard form of the damped quadratic, where the time scale has been chosen to make the natural frequency unit. The transfer function relating input to error is

$$\frac{e(s)}{R(s)} = \frac{1}{1+H_1} \tag{1}$$

and the characteristic equation of the system becomes

$$e(s)(1+H_1) = R(s) = 0 \tag{2}$$

The time function is

$$\frac{d^2e}{dt^2} + 2\zeta\frac{de}{dt} + (1+k)e = 0 \tag{3}$$

Note that first writing the expression in the Laplace transform serves no purpose. In fact, the Laplace transform loses its effectiveness in the analysis of nonlinear systems. Equation 3 can now be reduced to the first-order by substituting

$$y = de/dt \quad \text{and} \quad dy/dt = d^2e/dt^2 \tag{4}$$

The time function can then be written

$$\frac{dy}{dt} + 2\zeta y + (1+k)e = 0 \tag{5}$$

Dividing by $y = de/dt$ then yields

$$\frac{dy}{de} + 2\zeta + (1+k)\frac{e}{y} = 0 \tag{6}$$

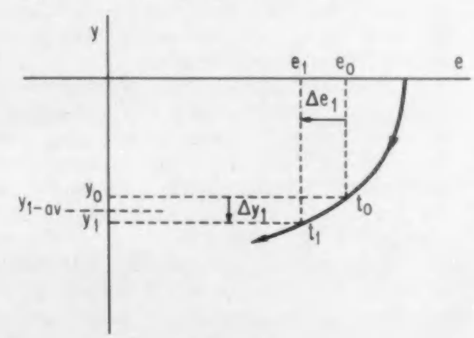
The location of a constant slope (dy/de = constant) may be found by rewriting Equation 6 as

$$\frac{y}{e} = \frac{-(1+k)}{2\zeta + (dy/de)|_{const}} \tag{7}$$

For given values of ζ and K, the isoclines or loci of constant slope may be plotted. For example, with ζ=0.5 and several values of dy/de, the plot of isoclines would appear as in Figure 2. Here y has been normalized to $1+k$.

The phase trajectory may now be plotted for any given initial conditions. In the above example these trajectories spiral in from any point to the origin. Thus the transient decays and the system is stable. Note how the plot of the trajectory depends on the value of k; as k increases the spiral moves further out on the y axis. Furthermore, the isoclines depend on ζ. As ζ increases, the spirals become tighter, and at ζ=0 they take up a constant radius

FIG. 3. Construction used to determine elapsed time for a given error interval.



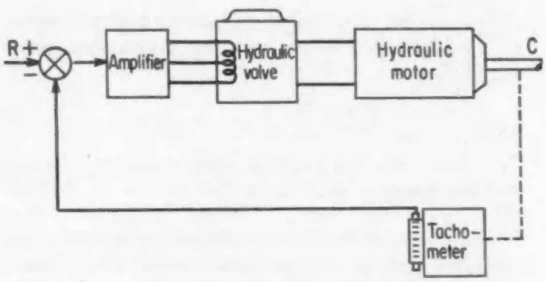


FIG. 4. Typical electrohydraulic velocity system.

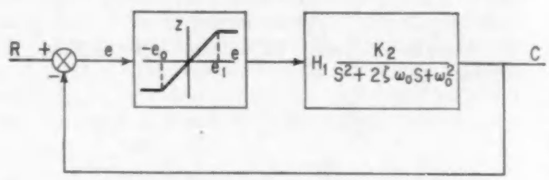


FIG. 5. Block diagram of a saturating servo—equivalent to the hydraulic system of Figure 4.

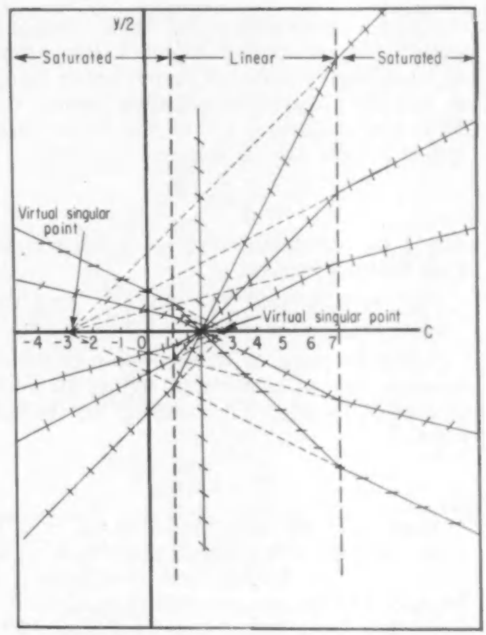


FIG. 6. Isocline construction for the hydraulic system, showing the singular point at plus 2 and virtual singularities at plus 3 and minus 3.

of curvature and become circles. Circular trajectories would represent conservative systems or an oscillator. With a negative damping factor the trajectory would diverge from the origin, indicating an unstable system.

Observation shows that the solution point in Figure 2 moves in a clockwise direction. Consider either trajectory as it cuts the horizontal axis to the right of the origin. Because here error is a positive maximum, the rate of change of error must become negative as time increases. Hence, the trajectory must have the direction indicated. In this example (and in general) the trajectory crosses the e axis at right angles since, along this axis, the rate of change of error is zero. However, the isocline of zero slope does not lie on the vertical axis. The spiral is twisted or skewed. This has suggested to Minorsky (Ref. 2) and others that a change of variables could translate the trajectory into a simple logarithmic spiral on some other set of axes.

Time, increasing along the trajectory, is implied on the plot, but it often becomes necessary to determine time explicitly. By definition, $y=de/dt$ and for small increments

$$y_{av} = \Delta e/\Delta t \quad \text{or} \quad \Delta t = \Delta e/y_{av} \tag{8}$$

where y_{av} represents the average value during the time increment. Figure 3 illustrates a method for finding the elapsed time between t_o and t_1. Both Δe_1 and y_{1-av} are determined graphically and used in Equation 8 to find Δt. The process is then repeated for succeeding Δe's. Since accuracy of the assumption depends on small increments, the Δe should be chosen so that Δy is not very large.

Piecewise linear systems

The isocline method readily adapts itself to the analysis of piecewise linear systems. Such systems operate in one of several linear states, depending on the amplitude of the input to the nonlinear element. One example might be an electronic system with a sharply saturating amplifier; another would be a mechanical system with limit stops on one of its degrees of freedom.

The hydraulic system in Figure 4 represents a third example. This system controls the velocity of a hydraulic motor with respect to the reference. Frequency response of the amplifier is flat, but the typical hydraulic servovalve has a double break at about 60 cps. A given differential current into the valve results in a flow corresponding to a particular output velocity. If the load is too light to affect the transfer, the expression for loop gain becomes

$$A = \frac{K_{amp}\,K_{valve}\,K_{tach}}{s^2 + 2\zeta\omega_o s + \omega_o^2}$$

$$\text{or simply} \quad A = \frac{K}{s^2 + 2\zeta\omega_o s + \omega_o^2} \tag{9}$$

Limiting or saturation could take place in either the amplifier or the servovalve. Assume it takes place in the amplifier, as this is slightly more complex.

Figure 5 shows a simplified block diagram of the system. As an alternate approach, this system will be considered in terms of output rather than error, so that the phase plane will show output, c vs. its time rate of change, $\dot{c}$. In the linear range the system transfer may be written

$$\frac{c(s)}{R(s)} = \frac{H_1}{1 + H_1} \tag{10}$$

and if the saturation curve has a slope of k_2, the time function becomes

$$\frac{1}{\omega_o^2}\frac{d^2c}{dt^2} + \frac{2\zeta}{\omega_o}\frac{dc}{dt} + \left(1 + \frac{k_1k_2}{\omega_o^2}\right)c = \left(\frac{k_1k_2}{\omega_o^2}\right)r \tag{11}$$

A singular point, or static solution to the system equation, may be obtained by setting the derivative of c equal to zero. Then solving for the singular point,

$$c = \frac{k_1k_2}{\omega_o^2 + k_1k_2}r \tag{12}$$

Assume the following conditions: $\omega_o = 377$, r is a step function with a magnitude of 4, $k_1 = 1$, and $k_2 = 142{,}000$. Under these conditions $c = 2$. Because of its low gain constant $(k_1k_2/\omega_o^2 = k = 1)$ the system has a rather large final error. To provide a more convenient scale on the phase plot, the time scale can be changed so that $\tau = \omega_o t$. Then, letting $y = dc/dt$, Equation 11 becomes

$$\frac{dy}{dt} + 2\zeta y + (1 + k)c = kr \tag{13}$$

Dividing by y and letting $\zeta = 0.5$,

$$\frac{dy}{dc} + 1 + \frac{2c - 4}{y} = 0 \tag{14}$$

Rearranging terms,

$$\frac{y/2}{c - 2} = \frac{-1}{1 + dy/dc} \tag{15}$$

The center section of Figure 6 shows the isoclines for the linear region. To determine the range of c over which this linear relation holds, consider the saturation conditions. For example, if the system is linear for $-3 < e < +3$, it must be linear for

$$-3 < (r - c) < +3 \tag{16}$$

Thus for the assumed case, where r equals 4, the system must be linear for $1<c<7$. Within this linear region, the isoclines are exactly the same as those in Figure 2, since the normalized equations are the same and the same slopes were chosen. Because it is always possible to normalize a system equation, the designer concerned extensively with piecewise linear systems might find it worthwhile to prepare a series of standard plots for various damping ratios.

For zero initial conditions, at $t = 0$, the output c_o must be zero and the error, e, must equal the input, r. Thus the system operates, and will continue to operate, in the saturated region until $c \gtreqless 1$. In the saturated region the linear relation no longer holds, and a new analysis must be made. Effectively the loop may be considered open and output c determined by the valve transfer H_1, with a step function $(z = 3)$ applied to its input by a saturated amplifier. Thus

$$\frac{1}{\omega_o^2}\frac{d^2c}{dt^2} + \frac{2\zeta}{\omega_o}\frac{dc}{dt} + c = \frac{k_2}{\omega_o^2}z \tag{17}$$

Not only has the characteristic equation changed, but the singular point has shifted to $c = 3$. Kalman (Ref. 3) terms this a "virtual" singularity since it exists outside the defined operating region of the saturated system. Thus the saturated system never reaches this point. Figure 6 also shows that for a saturated system with $c \gtreqless 7$ there is another virtual singularity at $c = -3$. The isoclines for the saturated regions, when extended, pass through their virtual singularities. Again letting $z = 3$ and $\zeta = 0.5$, Equation 17 may be written and simplified as follows:

$$\frac{d^2c}{d\tau^2} + 2\zeta\frac{dc}{d\tau} + c = kz$$

$$\frac{dy}{dc} + 2\zeta + \frac{c}{y} = \frac{kz}{y}$$

$$\frac{dy}{dc} + 1 + \frac{c - 3}{y} = 0$$

$$\frac{y/2}{c - 3} = \frac{-1/2}{1 + dy/dc} \tag{18}$$

Once the isoclines are plotted for both the linear and saturated regions, the complete trajectory can be sketched. Note that for a different step input, the entire plot must be recalculated.

Delta method

A somewhat less limited method for the graphical solution of the phase trajectory is the so-called "delta" method (Refs. 4, 5). This method consists of approximating short sections of the phase trajectory with circular arcs. As an example, consider the linear second-order system described earlier. Equation 3 may be written

$$\frac{d^2c}{dt^2} = -(1 + k)\left[e + \frac{2\zeta}{(1 + k)}\frac{de}{dt}\right] \tag{19}$$

For convenience, let

$$\tau = \sqrt{1 + k}\,t \quad \text{and} \quad y = de/d\tau \tag{20}$$

This will normalize the plot as in the previous example. Substituting these values and recasting Equation 19 to eliminate the explicit e terms,

$$(1 + k)\frac{d^2e}{d\tau^2} = -(1 + k)\left[e + \frac{2\zeta}{1 + k}\sqrt{1 + k}\frac{de}{d\tau}\right]$$

or

$$\frac{d^2e}{d\tau^2} = -\left[e + \frac{2\zeta}{\sqrt{1 + k}}\frac{de}{d\tau}\right] \tag{21}$$

where $(2\zeta/\sqrt{1 + k}\ de/dt)$ will be defined as δ. Thus

$$\frac{dy}{d\tau} = -(e + \delta) \tag{22}$$

Dividing by $y = de/d\tau$

$$\frac{dy/d\tau}{de/d\tau} = \frac{-(e+\delta)}{y}$$

or

$$y\,dy + (e+\delta)\,de = 0 \qquad (23)$$

and the solution of Equation 23 yields

$$y^2 + (e+\delta)^2 = R^2 = \text{a constant} \qquad (24)$$

With a constant δ, this represents the equation of a circle with radius R and center at $y = 0$ and $e = -\delta$, as shown in Figure 7. Although δ is not actually constant, it may be assumed so for small changes in variable (Δe and Δy). Plotting $\delta = f(y, e)$ on the phase diagram reduces the construction to a mechanical process. For this simple example, δ is a linear function of y only. Were it a more complicated function of several variables, separate plots could be made against the individual variables and the total δ found by adding the separate components at each point.

The following steps lead to the construction illustrated in Figure 8:

a) Establish the starting point using the initial conditions e_o and y_o.

b) Choose either e_1 or y_1 arbitrarily. (In this example y_1 is selected because δ has been plotted against y.)

c) Take δ_1 as the average value of δ between y_o and y_1.

d) Plot $-\delta_1$ on the e axis and swing an arc of radius R_1 with its center at $-\delta_1$, the arc passing through τ_o to the line y_1; this establishes e_1 and τ_1.

e) Repeat the process for successive values of y. Accuracy depends on the size of the increment Δy. For the case where δ changes rapidly, smaller values of Δy should be used to maintain accuracy.

Notice that the choice of $\tau = \sqrt{1+k}\,t$ was made so that Equation 24 would describe a circle. In general, where the delta method is used, the equation must take the form of Equation 23.

Another method of finding time on the phase plot may now be shown.

Since y has been defined as $de/d\tau$,

$$y_{av} = \Delta e/\Delta\tau \qquad (25)$$

When $\Delta\tau$ is small, it can also be assumed that

$$y_{av} = y_o + \Delta y/2 \qquad (26)$$

Combining these last two equations and rearranging terms,

$$\frac{2}{\Delta\tau} = \frac{2y_o + \Delta y}{\Delta e} \qquad (27)$$

Figure 9 illustrates the method used for establishing points along the trajectory separated by a given constant $\Delta\tau$. Note that the angle β is described by

$$\tan\beta = \frac{2y_o + \Delta y}{\Delta e}$$

Thus, from Equation 27,

$$\beta = \tan^{-1}\frac{2}{\Delta\tau} \qquad (28)$$

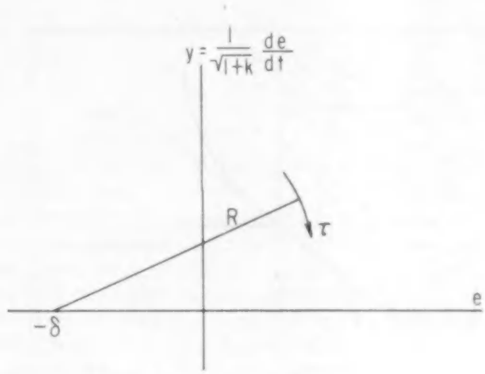


FIG. 7. Phase plane construction by the delta method.

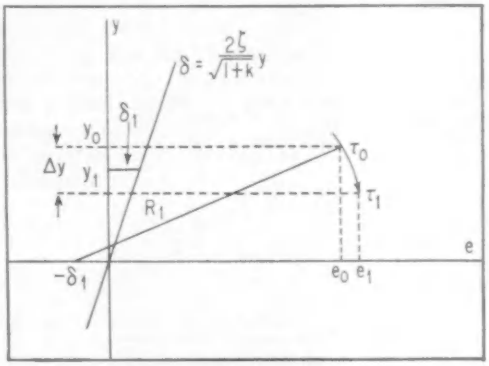


FIG. 8. Step-by-step procedure locates successive points on the trajectory.

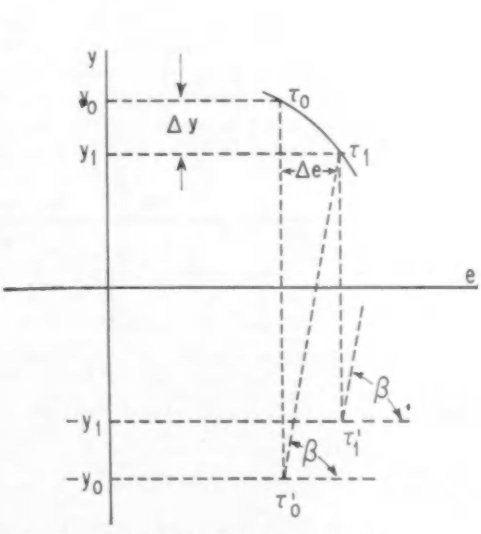


FIG. 9. Construction method for plotting equal increments of time along the trajectory.

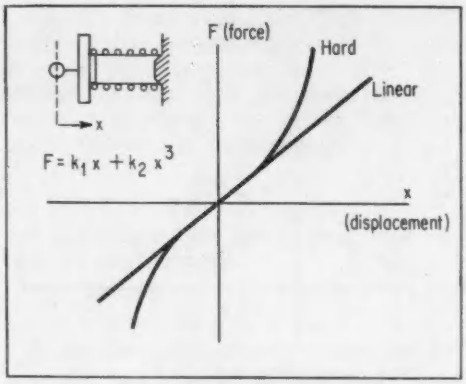


FIG. 10. Force-displacement characteristic of a "hard" vs. a linear spring.

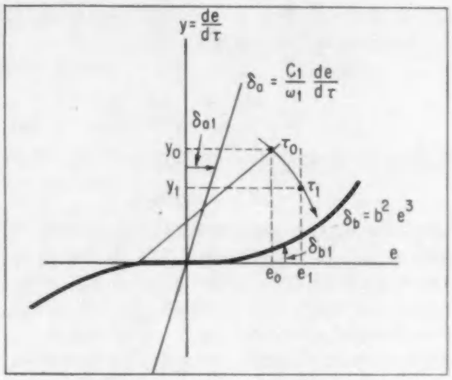
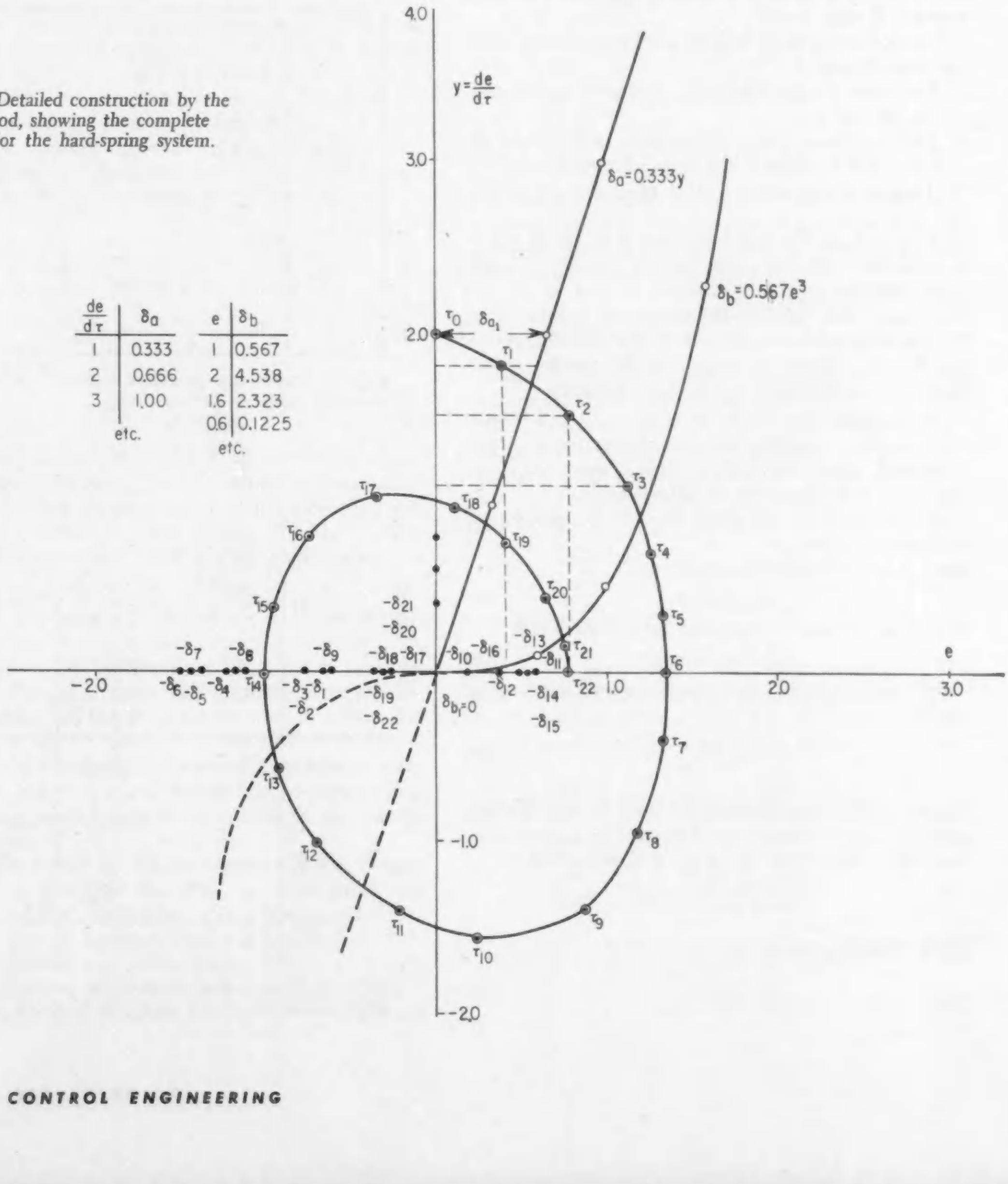


FIG. 11. Delta method of construction for a hard-spring system.

FIG. 12. Detailed construction by the delta method, showing the complete trajectory for the hard-spring system.



$\frac{de}{d\tau}$	δ_a
1	0.333
2	0.666
3	1.00
etc.	

e	δ_b
1	0.567
2	4.538
1.6	2.323
0.6	0.1225
etc.	

Construction follows three simple steps:

- Choose the desired $\Delta\tau$ and calculate the angle β from Equation 28
- On the trajectory, choose the starting point, τ_o, and establish the point τ'_o at e_o and $-y_o$
- Draw the construction line through τ'_o at the angle β; its intersection with the trajectory establishes τ.

Repeat the steps for successive points.

A small piece of pasteboard cut at the angle β simplifies the process. Accuracy of results, however, depends on accuracy of the construction. To check results, remember that as the trajectory approaches the e axis, velocity decreases and equal time increments should appear smaller and smaller. After the trajectory crosses the e axis, it bends to the left and gathers velocity. Equation 8 provides a useful check on the accuracy of the construction.

The graphical techniques described here are by no means limited to solving characteristic equations. A far more important application (important because in a nonlinear system response depends on the input) is in solving a system for a given driving function. If, in Equation 2, the input, R, were some driving function, $f(t)$, the analysis above would involve the quantity $(1 + k)\, e - f(t)$; in the delta method $f(t)$ would be part of the δ operator.

The isocline method may be convenient for investigating piecewise linear systems, but the delta method is usually superior when the nonlinearity is a continuous function of one or more of the variables. Either method becomes laborious when the driving function is a complicated function of time.

Delta method applied

Assume that in the hydraulic speed control system described earlier the nonlinearity occurs in the centering springs of the servovalve spool. The springs are hard rather than linear, and have the characteristic illustrated in Figure 10. The phase plane will be based on error.

For zero input, Equation 2 holds true and the time function for the system may be written

$$\frac{d^2e}{dt^2} + c_1\frac{de}{dt} + \omega_o^2(1 + a^2e^2)e + \frac{ke}{c_2} = 0 \qquad (29)$$

where c_1 is the viscous damping coefficient, c_2 the inertia coefficient related to the volume of the nozzle chambers, k the gain through the amplifier to force on the flapper, and ω_o the natural frequency of flapper vibration in the linear range of the spring. Combining coefficients in Equation 29,

$$\frac{d^2e}{dt^2} + c_1\frac{de}{dt} + \omega_1^2(1 + b^2e^2)e = 0 \qquad (30)$$

If the time variables are changed so that $\tau = \omega_1 t$ and $d\tau = \omega_1 dt$ the equation can be further simplified to permit identification of the δ quantity. Thus

$$\frac{d^2e}{d\tau^2} + e + \underbrace{\frac{c_1}{\omega_1}\frac{de}{d\tau} + b^2e^3}_{\delta} = 0 \qquad (31)$$

Here is a case where δ can be broken into two parts, δ_a and δ_b:

$$\delta_a = \frac{c_1}{\omega_1}\frac{de}{d\tau} = \frac{c_1}{\omega_1}y$$

$$\text{and} \quad \delta_b = b^2e^3$$

Figure 11 shows both these portions of δ erected on the phase plane as construction aids. Assuming initial conditions at τ_o, the process is as follows:

- Select an arbitrary increment on the e axis and draw the vertical construction line through the e_1. For accurate results, choose a small Δe.
- Estimate the location of y, and draw a light horizontal construction line through this point.
- Find $\delta_1 = \delta_{a1} + \delta_{b1}$. Again, average values are picked.
- Swing an arc with center at $-\delta_1$ on the e axis through the point τ_o. The intersection of this arc with the construction line through e_1 should establish the point τ_1.
- If the construction line through y does not also intersect this point, choose a new value of y_1, correct δ_1, and redraw the arc. The values selected are correct when the arc cuts through the point y_1, e_1. The process is then repeated for successive values of e.

Taking a concrete example to emphasize the technique, assume the coefficients of Equation 29 have the following values:

$$\left.\begin{aligned} c_1 &= 164 \\ c_2 &= 0.01 \\ k &= 1{,}000 \\ \omega_o &= 377 \\ a^2 &= 0.858 \end{aligned}\right\} \text{ in consistent units}$$

Then the constants of Equation 30 must be

$$\omega_1^2 = \omega_o^2 + \frac{k}{c_2} = 242{,}000$$

$$b^2 = \frac{\omega_o^2}{\omega_1^2}a^2 = 0.5$$

$$c_1/\omega_1 = 164/492 = 1/3$$

Figure 12 shows the phase portrait of the system for an initial condition. The increments chosen are large and some of the construction lines have been left in as an aid in following the method.

Part II of this series will cover the characteristic configurations most often found on phase plots, and their interpretation.

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Building Reliability Into Digital Process Control Systems

THE GIST: Nurtured by academic imagination on the one hand and the promise of handsome economic payout on the other, computing control has now attained acceptance by several users in the process industries. Just how much the (digital) computer must increase throughput, improve quality, and reduce operating costs to fulfill its promise depends on the process to be controlled. But none of these benefits can be obtained if a forced outage due to a failure occurs anywhere in the system—including the computer. Thus, the computer's own reliability and its effect on overall system reliability becomes of paramount importance in considering an integrated digital computer system.

Simple circuits and functional designs of computer sections, and selecting, testing, and derating components keep computer failures to a minimum. Should one occur, however, its effect on process operation is minimized by fail-safe circuits, output-range limits, and automatic transfer to manual control. Through such engineering features, the author maintains, a digital computer control system reduces the overall cost of process operation and keeps down its own maintenance costs.

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Anyone considering integrating a digital computer into a control system for an industrial process must ask several questions:

- ►Can the system be designed so that computer failure will neither damage nor upset the process?
- ►Will instrument failure mislead the computer into upsetting the process?
- ►What will be the effect of such an integrated control system on the maintenance costs of the process equipment?
- ►Can maintenance cost and downtime be held to a negligible amount?

Previous experience with data logging systems and digital computers in business applications may provoke skepticism about the basic reliability of computer-control systems. And the realization that these systems must operate on-line continuously may add to this skepticism. However, satisfactory answers to the above questions require appraisal of all aspects of the overall system, including special features that may ease reliability requirements.

The loss due to individual failures in a system varies widely, from the low cost of a vacuum tube and its replacement time to the high cost of repair of major process equipment, with the attendant loss of several weeks of operating time and process output. The overall annual cost C_f due to the failures of equipment anywhere in the system is expressed as the sum of the cost of individual failures times the frequency (per year) of their occurrence, plus the fixed annual cost C_m of the maintenance organization. C_m includes the costs of preventive maintenance schedules and investment in spare parts. Thus:

$$C_f = \Sigma \text{ (frequency of occurrence) (cost per occurrence)} + C_m.$$

A sound attack on the reliability problem must begin by reducing failure frequency to an absolute minimum, preferably to no failures at all, for to realize the anticipated earning power of the investment, a high-cost computing-control system must work well and continually. Preventive maintenance aims at holding down the cost of replacing a part. Such maintenance may actually increase the frequency of replacements (or failures, depending on one's definition) since parts are discarded before they have deteriorated sufficiently to cause an actual failure. Failures which are not or cannot be caught in this way should be minimized by fail-safe features.

Reliability of digital computer process control will be discussed with the typical system represented by Figure 1 in mind. Here, temperature, pressure, flow, level, and analytical-instrument measurements are fed continuously to the computer. Pneumatic

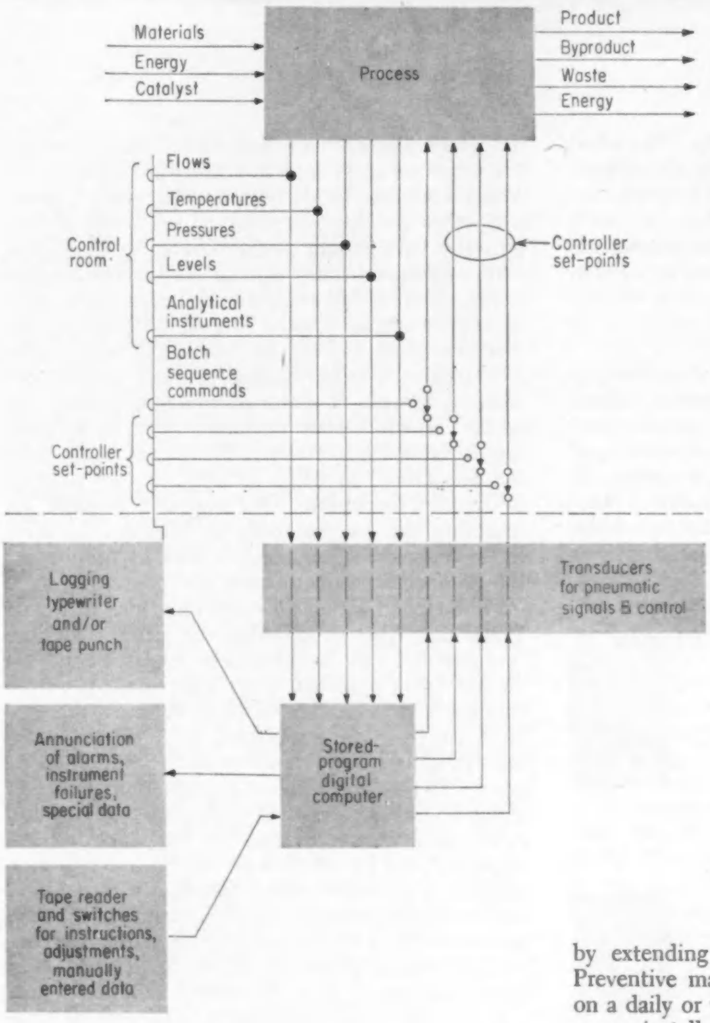

FIG. 1. The typical integrated process control system using a digital computer consists of the process and instrumentation, above the dashed line, and the digital computer and transducers, below.

FIG. 2. Etched wiring and permanent components improve system reliability.

signals are transduced to electrical signals for compatibility. Periodically, the computer performs appropriate calculations, based on programs stored in its memory section, and readjusts its electrical outputs to modify the set-points of conventional controllers. The computer's memory has room for many instructions and constants which can be changed either by a human programmer or by the stored program. The memory also stores raw data and intermediate and final results of processed data.

The system of Figure 1 consists of three main sections: the computer, the process, and the associated instrumentation and control equipment. The system's cost of maintenance may be evaluated by estimating the probable cost of failures in these individual sections.

Computer reliability

The reliability of a continuously-operated process control computer must surpass that of the business or scientific machine by a substantial factor, for it will not be possible to make up lost working time by extending a 24-hour operation into overtime. Preventive maintenance, including chassis rotating, on a daily or weekly basis would be unacceptable in many installations. Therefore, emphasis must be less on detecting and correcting failures and more on preventing failures from occurring at all.

Computer reliability is achieved principally in two ways: by functional design and by selecting, testing, and applying individual components. Functional design, of primary importance to both the computer manufacturer and user, involves compromises between equipment simplicity on the one hand and operation speed, capacity, and flexibility on the other. For instance, the computer's control and arithmetic sections may be kept simple by limiting the number of individual instructions the computer must recognize in its program. This would mean more work for the programmer of a scientific computer, for it would require that he write additional steps into its constantly changing programs. In a process control computer, however, such reprogramming will be relatively infrequent and a simple instruction system may be adequate.

Another compromise involves the computer memory's writing characteristics. Such permanently stored information as programs for control computations, data logging, alarm scanning, and other service work occupy most of the memory and need

not be varied during normal operation. The input and output variables, their accumulated averages, variable parameters, and "scratch pad" areas—the changing data—generally occupy less than one-fourth of the total memory. Therefore, if the computer is designed so that only a limited area of its memory accommodates changes in normal operation, the permanent program can be safeguarded automatically against accidental erasure or writing.

Functional design for reliability also means not using equipment that can be troublesome. About 90 percent of the malfunctions encountered in business and scientific computers arise in mechanical input and output equipment, printers, and magnetic and paper tape and punched card handlers. These failures can be avoided in the process control digital computer system by direct transfer of signals from the process to the computer's memory and from the memory to the process, i.e., with no moving parts other than those in the conventional instrumentation and transducers and in sealed relays.

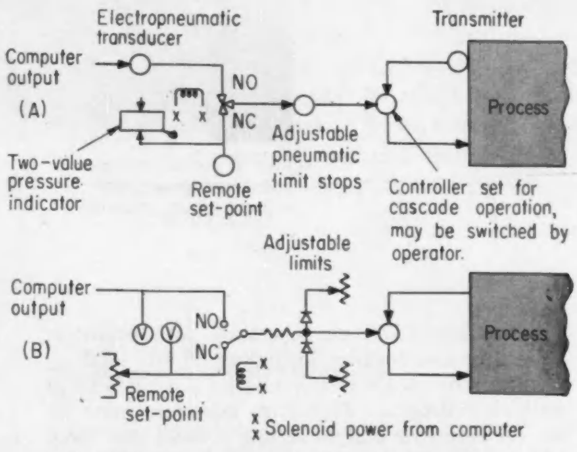

FIG. 3. The computer automatically determines the set-point for the conventional controller. Adjustable limit stops restrict the range to safe desired values, and the solenoid operated valve (or switch) enables the operator to take over manual control at will or at failure of computer power.

This direct transfer often is a major argument for using a special-purpose computer on-line to control a process. System inputs through a card or tape reader can be held to an absolute minimum, and then only for loading the initial program, informing the computer of startup or shutdown, changing a limit of a variable, or making an incremental change in loading of a pump. The alternative to on-line computing, sharing a general-purpose computer with nonprocess activities, requires transmitting information from a data logger in tape or card form, and transmitting printed control signals from the computer to the control board.

The computer's many individual components are the subject of an even more detailed reliability study. Much work has already been done in guided missile and other military programs to relate the overall reliability of a system to the number of its components and the reliability of individual components to testing methods and environmental conditions. Such experience can be adapted to a digital computer for process control, which might have 6,000 active parts, including transistors, diodes, resistors, condensers, and transformers. For this computer to average one month of continuous operation between failures, the individual components themselves must average one failure in 6,000 months, or 500 years of continuous operation! This imposing demand for reliability can be met only by high-quality, well-sealed, permanent components, and by minimizing the number of nonpermanent components.

Flush-etched wiring on epoxy-resin boards, Figure 2, and new types of solderless connection (for conventional wiring) answer these requirements. So do hermetically sealed relays with mercury-wetted contacts and proper arc suppression across the contacts, for these are guaranteed for 1 billion operations (and have been known to reach 3 billion operations with no sign of failure after the initial burn-in period). Other safeguards: premium-type vacuum tubes conservatively derated for long life, and stabilized circuits for satisfactory operation over a wide range of component values. Finally, in recognition of the burn-in characteristics of many components, factory checkout of the computer, including the control and logging programs, should be planned so as to exercise components for several hundred hours.

It must not be assumed that because care has been exerted in the design, manufacture, and checkout of a process control system, permanent and random nonrecurring failures will not occur. Fail-safe philosophy as it applies to a computer control system design has two principal objectives:

1. Wherever possible, to detect failures before they have any effect on the process and determine effective remedial action.

2. To minimize the effect on the process of failures that cannot be preceded by a warning.

Consider first the steps taken within the computer program toward accomplishing these objectives. Most failures in the computer itself can be detected in time by requiring the computer to perform a test problem immediately before computing a new output value. The test problem exercises all computer instruction codes and portions of the memory. The computer may be programmed so that failure of this test idles it and warns the operator to take over control of the process. Meanwhile, all outputs can maintain their last calculated values.

A digital computer's process-control functions lend themselves readily to a reasonableness check. Usually, the computer measures process variables and periodically repeats a set of calculations. A simple check,

to guard against a random nonrecurring failure that could affect the calculation of any individual output, consists of specifying for each output the maximum increment by which a new calculated value differs from its previous value. When this increment is exceeded the output is left at its present value until the calculation has been repeated and checked, either immediately or on the next programmed pass through the calculation. A variation of this approach is to allow the output to change by a small increment: if the change is due to a random error the value of the variable is reestablished properly on the next pass. This second approach is superior, in some situations, in that it also sets a maximum limit on control-point change, smoothing the normal control action for the process.

Failure of a component in the final stage of an output or loss of power by the computer may take immediate effect, with no warning to the operator. To understand how these effects may be minimized, consider how the computer is connected to the process control points. In Figure 1, the instrumentation and set-point controllers above the dashed line comprise an independent conventional process control system which may be used during periods of computer maintenance, program modification, system startup and shutdown, and, of course, as a standby control system.

Figure 3 details the way the computer controls the process by adjusting the set-point of individual control loops. (The computer could replace the controller by measuring the variable directly and adjusting the valve or output control point, but in many cases this would represent an impractical and uneconomic use of an expensive mechanism.) The first step in minimizing the effect of any sudden local computer failure is to limit the output control range to the minimum necessary for satisfactory control of the process. This is done by means of the inherent scale limits of the transducer or controller hardware, or more conveniently by setting the continuous analog limit stops, Figure 3, so that they restrict the computer's control to that needed for startup, shutdown, or other infrequent modes.

In the event of sudden total failure, such as loss of power in the computer, control of all outputs must be automatically transferred to the standby system. This transfer is actuated by removing the power from the computer to the solenoids, Figure 3, for all control loops. The system must be designed so that the operator can operate any solenoid at will and thereby obtain control of any output set-point or return control of any variable to the computer. To minimize bumping the process, each variable is provided with a two-pointer indicator which continuously displays the computer output and manually-set reference point in a convenient form for comparison.

Pneumatic control systems may be arranged so that the removal of power from the solenoid valve in Figure 3A holds the control pressure at its present value, allowing the operator to manually match reference points and complete the transfer of each output without bumping. With this arrangement, daily tracking of the computer's outputs by the operator is not necessary; however, all equipment and operating personnel in the standby system must be drilled often enough to retain operating efficiency.

Instrumentation reliability

A digital computer will probably have only a secondary influence on the frequency of related instrument failures. But it can aid instrument maintenance by giving early warning of any failures that do occur. It can watch for hardover conditions, for readings that do not fluctuate when they should, and for excessive drift in calibrations.

The effect on the process of instrument failures would be far greater than in conventional systems if the computer blindly followed instrument readings without discriminating between valid and invalid data. The input system (through the selection of data ranges) and the program should be organized so that the computer not only recognizes and announces instrument faults but also makes suitable allowances for them in executing its control equations. Then, instead of using faulty data, the computer may refer to a secondary source of data, to the last value of data, to an arbitrary constant, or to data derived from other variables. These provisions add to the bulk of the computer's program, but they are the necessary price of the full integration of a complex control system.

Process reliability

In many installations reductions in process maintenance will outweigh additional computer maintenance. Maintenance scheduling of process equipment may benefit by having the computer perform periodic checks on such items as heat exchanger and pump efficiencies and catalyst poisoning. Maintenance checks can be permanently stored in the computer's memory or loaded in from permanent tapes each time they are needed, sharing space with such other infrequently used programs as computer maintenance and process startup and shutdown.

The digital computer control system provides, as a by-product of process control, improvement of process reliability. It acts as a sophisticated limit-checking alarm system, warning of dangerous or near-dangerous conditions. It can be programmed to take appropriate control action, following an alarm, through its regular control output or through specially assigned relay outputs. It detects such conditions not only by standard limit-checking but also by checking the deviation of variables from calculated set-points, by extrapolating trends to predict impending limit excursions, by testing correlation between different variables to detect obstructions, and by making material and energy balances to detect leaks and loss of process efficiency.

Get the Most Out of Your Servomotor

THE GIST: The simple electromechanical servomotor is a far more flexible device than most applications engineers realize. So flexible, in fact, that optimum use often leads to a substantial simplification in control system design and packaging. This optimum use is achieved in several ways: by thoroughly exploiting the capabilities of the many standard motors that are available, by cooperating with the motor manufacturer to obtain motors with unique characteristics, or by using one of the common motor packages in which such things as gear trains, dampers, and tachometers are included within the motor frame. Author Davis discusses many modifications, both minor and complex, and points out how they can be used to extend a servomotor's function.

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The place to start in selecting a two-phase ac servomotor is with the standard models. Figure 1 shows the outline and performance of the standard Bureau of Ordnance Mark 7 servomotor, a 400-cps component used very widely in military automatic control systems. It is a good general-purpose motor that will satisfy a broad variety of applications. Since Mark 7's are available from many sources, and since recognized standards exist for both performance and reliability, selection and purchase should present no special problem.

There are many standard Bu-Ord motors and if one of these satisfies system requirements it is certainly the one to use: it is a proven component, cheaper and more readily available than a "special". But sometimes there is no standard that exactly fits, and at other times use of a modified design permits system simplification, miniaturization, and improved reliability. Under these conditions a special may be called for.

Some special models are readily available from servomotor manufacturers, others are not. The following points out available special features and the benefits they provide.

1. SPECIAL LINE VOLTAGE RATINGS

The servomotor manufacturer can produce an assortment of designs, simply by using special windings. Thus, without making major mechanical changes or doing much expensive retooling, it is possible to create a large variety of special motors. Winding modifications, then, constitute a flexible and low-cost means of achieving special performance.

One of the simplest modifications that the servomotor manufacturer can make is to change the rated line voltage. For example, a standard motor rated at 115 volts on its main and control phases can yield essentially the same performance when the two phases are wound for some other rated voltage (which need not be equal for the two phases). Common ratings are 57.5 volts for magnetic amplifier operation, and 40 volts and 67.5 volts in transistor circuits.

High voltage ratings require wire that is so fine as to be uneconomical, while very low voltages require wire that is heavy and difficult to handle. Between these two extremes, however, voltages can be varied easily by winding changes. Special ratings are particularly important when, for reasons of economy or miniaturization, it is necessary to avoid transformers.

Sometimes motors are designed so that the control field will operate at either of two voltage ratings. For example, many Bu-Ord motors have a divided control winding with a series-rated-voltage of 115 volts and a parallel-rated-voltage of 57.5 volts. Any pattern such as this (for instance, 80 and 40 volts) is feasible.

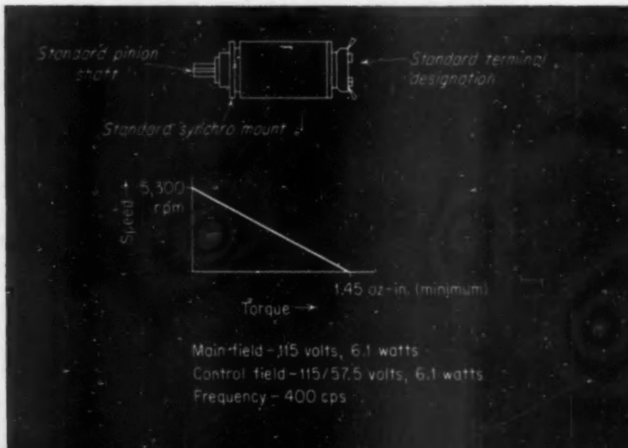


FIG. 1. A Standard Bu-Ord motor (such as this Mark 7) is the unit to use if it satisfies system requirements.

2. MINIMIZING CONTROL-FIELD POWER

Special windings can be prepared that minimize the required control field power, and thus permit the use of a smaller servo amplifier. The amount of main field power that is used is not too important, however, because it is taken directly from the power supply; the only consideration is that the temperature rise of the servomotor be limited to a safe value. This suggests that a simple way to reduce control-power requirements is to apply unbalanced power to the separate phases.

For example, assume a servomotor with a power rating of 6 watts per phase. Total permissible dissipation is 12 watts, based on allowable temperature rise. The question is, how much does performance deteriorate if less power were put into the control phase and more power into the main phase, the total power remaining the same?

This question can be answered by considering only the stall or zero-speed condition. Since servomotor torque is proportional to the product of main- and control-field voltages, keeping the main-field voltage constant will vary the torque linearly with control voltage. Power varies as the voltage squared. Thus, the stall torque varies as the square root of the product of the main- and control-field powers. Dividing the fixed total of 12 watts into a main-field power of 9 watts and a control-field power of 3 watts, the ratio of torque for the new condition to torque under balanced conditions is given by:

$$\text{Torque ratio} = \frac{\sqrt{9 \times 3}}{\sqrt{6 \times 6}} = 0.866$$

Therefore, cutting control field power in half reduces stall torque by merely 13.4 percent.

This particular design variation may be carried out using other values of power, too. A reduction of control power to as little as 1 watt will still provide significant output torque: a 1-watt control winding with an 11-watt main winding cuts available torque by less than half, although control power is one-sixth of rated.

Some points must be checked by the servomotor manufacturer. Heating will not be uniformly distributed, and hot spots will develop in the main winding. Similarly, saturation will result because of the high main-field flux. Saturation flux density varies as the square root of the main-phase power. But once the power ratings have been arrived at, the motor can be rewound to suit any required voltage rating.

3. CHANGING THE NUMBER OF POLES

In general, it is desirable to wind a servomotor for as many poles as possible consistent with efficiency requirements. In other words, a large number of poles tends to give higher stall torques and lower no-load speeds, a combination that means good inherent motor damping, but there is a maximum beyond which it is unwise to go. This limit is established by the magnetizing current drawn by the servomotor. The greater the number of poles, the greater the percentage of input power that is dissipated as magnetizing losses, and the smaller the portion that is transferred to the rotor to generate torque.

Where high mechanical power output, and not damping, is the principal performance requirement, fewer poles give greater efficiency. Thus, more watts of shaft power can be drawn from a four-pole motor than from an eight-pole motor in a given frame size, despite the higher stall torque of the eight-pole unit. All this simply means that winding with fewer poles may be the answer in some cases, winding with more poles in others.

4. DIRECT PLATE OPERATION OF A SERVOMOTOR

Miniaturization of servomotors has necessitated designs in which control-field impedances can be driven directly from the amplifier output circuits, and not indirectly through an output transformer. Figure 2 shows a common variation, in which the motor windings are designed to directly match the output circuit of a pair of triodes. By proper design the windings can be arranged so that the net dc magnetization in the motor core is zero. This prevents the saturation as well as the extra drag and cogging that would be introduced. In specifying this type of servomotor, insulation requirements must be taken into account because of the high B + voltage between the phases. So must dissipation in the separate halves of the motor winding, although in class-*B* operation this is negligible since the quiescent current is approximately zero.

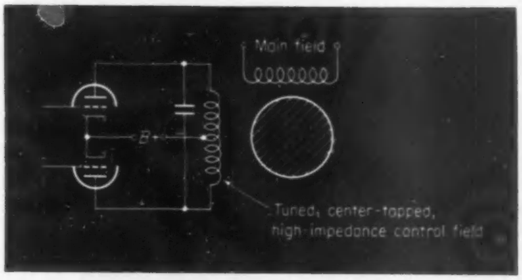


FIG. 2. Direct plate operation of a servomotor.

5. TECHNIQUES FOR SHIFTING MAIN-FIELD PHASE

There are a number of ways of shifting the phase of the voltage applied to the main field of the motor. If a polyphase source is available the required phase-shifted voltage can be obtained directly; in other cases, a capacitor can be incorporated directly in the motor main field, as shown in Figure 3A, to shift the winding phase 90 deg with respect to the line. The principal difficulty is that resonance tends to build up motor-winding voltage above line value. In a typical servomotor it is possible for a 115-volt line to develop 150 volts across the motor when the main field is tuned to a 90-deg phase shift.

Figure 3B shows one method for solving this problem: a transformer steps down line voltage to an ap-

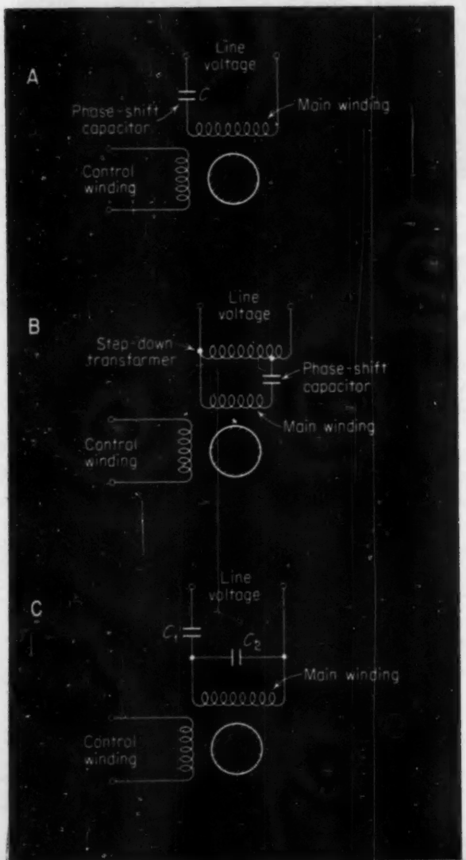
propriate value so that when the tuning capacitor is inserted in series with the main field, this field is subjected to rated voltage. When properly tuned, the motor voltage will be Q times the line voltage, where Q equals the tangent of the power factor angle.

One way to avoid this transformer is to use two capacitors, as shown in Figure 3C. The disadvantage is the necessity for two capacitors. It can be shown that the sum of the two capacitors is equal to what would be required to series-tune the motor main field for a 90-deg shift (Ref. 1). The ratio of the capacitors depends on line and motor voltage ratings.

Probably the most convenient solution to the problem of main-field phase-shift is to design the motor so that with a single-series phase-shifting capacitor (as in Figure 3A) it will operate properly at the tuned voltage across the winding when rated line voltage is applied. In the example given above, a line voltage of 115 volts is stepped up to approximately 150 volts through a series-tuning capacitor of 0.18 mf. However, since the main field was designed for 150 volts, the motor operates at its rated power and gives required performance.

As a general rule, the capacitance required for tuning or phase-shifting purposes varies inversely with the square of the voltage. Thus, low-voltage units require high capacitance ratings, even though the voltage rating of the capacitor is proportionately lower. The net result is to make low-voltage-unit capacitors rather bulky.

FIG. 3. Techniques for shifting main-field phase.
A—Series capacitor shifts phase 90 deg, but resonance builds up winding voltage above line voltage.
B—Step-down transformer compensates for resonant build-up.
C—Capacitors can be adjusted to provide rated main-field voltage and 90-deg phase shift.



6. IMPROVING SERVOMOTOR DAMPING

In addition to its basic function, developing mechanical power at the output shaft, a servomotor may be required to supply damping for stabilization purposes. Damping produced directly at the servomotor shaft is particularly helpful in the presence of such nonlinear characteristics as saturation and backlash, and is insensitive to variations in line frequency and to quadrature and harmonic components in the electrical signals.

There are many ways of producing damping at the motor shaft. The speed-torque curve of a two-phase servomotor shows that torque decreases with speed, which is the same as saying that there is a drag torque proportional to speed exerted on the motor shaft (Ref. 2). This drag torque constitutes essentially pure viscous damping. Inherent servomotor damping is the simplest type since it is designed directly into the servomotor and can be optimized by selecting the proper number of poles and by adjusting the conductivity of the rotor squirrel-cage bars.

If the inherent viscous damping of a standard motor is inadequate, supplementary damping can be provided by modifying the rotor skew. It has been found, for example, that the no-load speed of a size-10 servomotor can be reduced from 6,700 to 3,500 rpm simply by reducing the skew. There is no significant reduction in stall torque. This technique is useful in medium-performance servomechanisms, where an additional margin of stability is required.

For additional viscous damping, a drag cup (Figure 4) of a low-inertia, high-conductivity material such as aluminum can be attached to the motor shaft, and rotated in the field of a stationary permanent magnet. The result is a viscous drag proportional to speed. There are variations in which damping can be changed by a screw-driver adjustment. Figure 5 shows the speed-torque curves for the maximum and minimum adjustments on the drag damper of a typical servomotor.

Figure 6 shows some less-important methods of developing viscous damping. These methods may be compact and inexpensive, but they have a major disadvantage: they introduce dc in the windings to cog the servomotor and thus increase the starting voltage. The methods employing the rectifiers, Figures 6A and 6B, are useful when a system has already been designed and constructed and a compact way of introducing additional damping is required.

Inertial damping—a somewhat more complex form of damping that has special advantages—can be obtained by adding the mechanical components shown in Figure 7. Under a constant-speed condition, the servomotor, through the drag-cup coupling, causes the magnet assembly to rotate. Magnet speed and shaft speed will be essentially equal, any differential being the result of residual bearing friction. Thus there is no reduction in output torque caused by drag on the motor shaft. But when the servomotor is at rest in an equilibrium position, any tendency to oscillate is damped by viscous coupling to the relatively massive magnet, which cannot follow rapid oscillations. The inertial damper thus provides viscous drag at null to damp out incipient oscillations, but does not subtract output torque at the

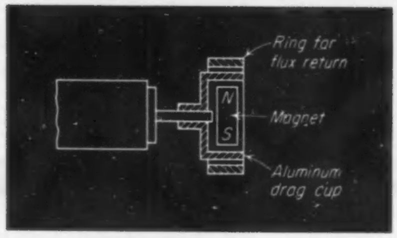


FIG. 4. Magnetic viscous damper on servomotor shaft.

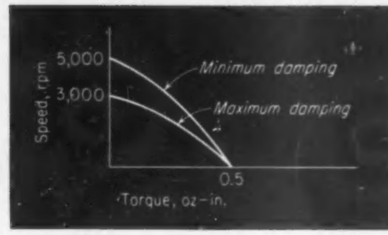
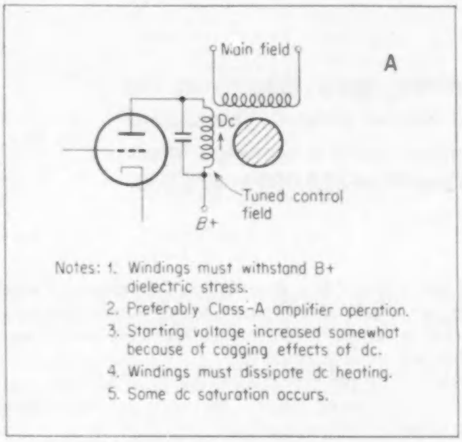
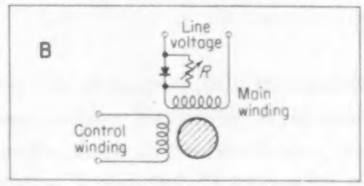


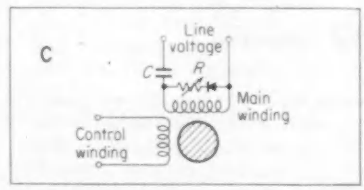
FIG. 5. Range of damping available from motor with adjustable magnetic viscous damper.



A—Viscous damping derived from quiescent dc in motor control winding.



B—Series rectifier provides dc damping: R is the damping adjustment.



C—Series phase-shift capacitor C and shunt rectifier for dc damping: R is the damping adjustment.

FIG. 6. Damping is sometimes obtained by using electrical networks.

motor shaft. This technique is useful where low velocity errors and high mechanical output are required. However, it does reduce servomotor accelerating ability, since the heavy magnet must be brought up to motor speed.

An inertial damper on a servomotor shaft is analytically equivalent to an ordinary lag-lead network at the servoamplifier input. When the break points of the lag-lead network are specified the motor designer can translate these into damper parameters (Ref. 3).

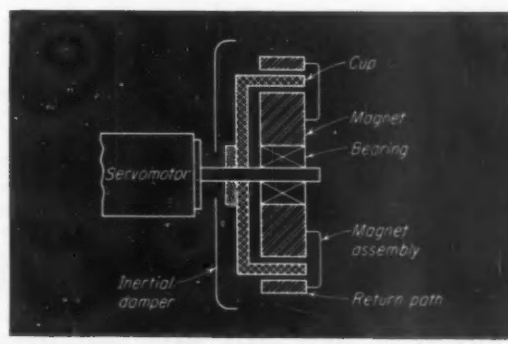


FIG. 7. Inertial damper on servomotor shaft.

7. PACKAGING OTHER SYSTEM COMPONENTS WITH THE MOTOR

FIG. 8. A few of the common motor packages

A. Motor + gearhead
(possibly including antibacklash gears)
B. Motor + gearhead + slip clutch
C. Motor + tachometer
(for either damping or integrating)
D. Motor + brake
E. Motor + viscous damper
F. Motor + inertial damper
G. Motor + gearhead + tachometer + brake
H. Motor + gearhead + damper + coupling + potentiometer

Probably the greatest flexibility in system packaging can be achieved by combining within the motor frame many of the components that are frequently used separately. In addition to simplifying the design, this process obviates the considerable engineering effort needed to get the separate components to work satisfactorily together. Figure 8 lists some of the common packages extensively used in control systems. Their variety is almost unlimited, making close cooperation between the systems engineer and the motor designer an indisputable necessity.

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2. STABILIZING INSTRUMENT SERVOS BY INTERNAL MOTOR DAMPING, Gerald Weiss, "Control Engineering", December 1956, pp. 84-87.
3. FLYWHEEL OSCILLATION DAMPERS, Sidney A. Davis, "Control Engineering", December 1954, pp. 29-32.

A Control Earning Index

PART II—Case Histories

Part I of this article (CtE, August, p. 67) described the steps in determining the earning indices of proposed measurement and control systems. This second part covers actual industrial applications. It reports control earning indices that range from 6 to 15 for control systems that cost from \$25,000 to \$75,000.

W. E. VANNAH, Control Engineering

A control earning index applies to tangible economic earnings that can be realized with improved measurement, test, and control equipment. It is equal to the first-year improvement in operating expense divided by the sum of the control system cost depreciation assigned in the first year and the annual maintenance costs charged to the control system.

CASE HISTORY I

Extrusion of plastic film—materials savings

Controllability was proved physically with a trial installation and earning power was estimated.

Economic Model

1. 840,000 lb of plastic film per extruder per year
2. Cost of input polymer, 35 cents per lb
3. Operating costs unknown
4. One die change or specification change per day

Figure 1 (also used in Part I, August) compares the performance, in terms of product gage distribution, achieved by manual control without continuous non-contact gaging (termed "blind" control here), manual control with continuous gaging, automatic control on correct target, and automatic control on a reduced target. The peaking of the curves demonstrates the progressive increase of production on target and the reduction in tolerance that occurred when control was changed from blind to automatic. There was also a general downgage shift from the over-gage product that had been deliberately produced with blind control to make certain that minimum gage would be above the lower tolerance limit. With blind control, product averaged 0.0622 mils over the desired 0.9 mils. Manual control from display of continuous gaging reduced this to 0.0174 over-gage. Fully automatic control dropped the mean deviation to 0.005 under-gage or to within 0.6 percent of perfect control of average thickness.

Earning Index

Because operating costs were unknown, only savings due to decreased consumption of polymer could be estimated. The area between the curves for blind control and fully automatic control represents real material savings of:

840,000 lb per year x 0.0622/0.9 = 58,000 lb

Reduction of target to a point where 94 percent of total production is still above the 0.8 mil lower tolerance limit, that is, target reduction to 0.86 mil, would save an additional amount equal to:

840,000 lb per year x 0.04/0.9 = 37,000 lb

The economic saving earned by more precise control and by target reduction is, then,

95,000 lb x 35 cents per lb = \$33,250

Decrease of scrapped film during changes in dies and specifications came to only 5 lb per change, but it meant

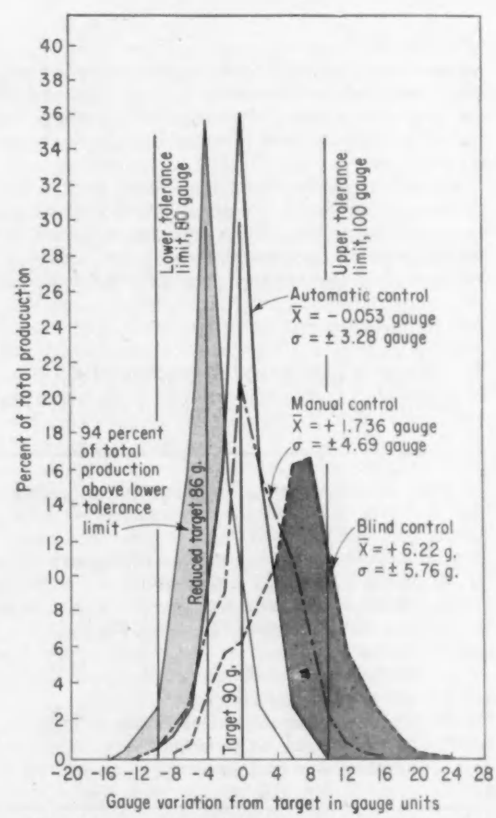


FIG. 1. Bar graph of plastic film quality distribution shows that processes not equipped with adequate instrumentation run quality higher than necessary, and that fully automatic control decreases the percent of off-target production.

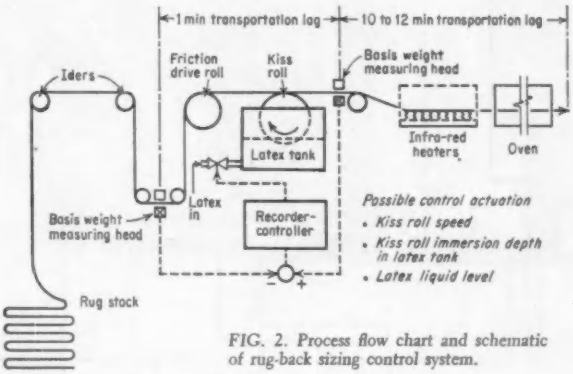


FIG. 2. Process flow chart and schematic of rug-back sizing control system.

an economic saving of 1 change per day x 5 lb per change x 350 production days x 35 cents per lb =

$610 per year

The total tangible economic saving per year is $33,900 for a $24,500 investment in improved measurement and control. If the system cost is depreciated linearly over a period of five years, it earns $33,900 minus $4,900, or $29,000 each year, less instrument maintenance charges. Its earning index is about 6.

Earnings not reported resulted from increased machine speed, reduction in scrap and customer rejects, and use of the continuous gage to investigate die adjustment, faulty dies, temperatures of extruder and supercooler, and machine-speed-and-weight relationships.

CASE HISTORY II

Rug-back sizing—time and material savings

Survey measuring kits proved controllability; tangible earning power was estimated. Figure 2 shows the process flow, the locations of the measuring instruments, and the possibilities for final control elements. The system determined the weight of latex sizing by automatically taking the difference between the basis weight measurements before and after the rug passed through the latex tank. This meant a measurement lag of 1 min, instead of the 10 to 12 min that would have existed had the measurement been made at the curing oven exit.

Economic Model

1. $2\frac{1}{2}$ million sq yds of rug processed per year
2. Total processing cost, $2.50 per sq yd, including cost of latex
3. Sales price $5.50 per sq yd
4. Margin $3.00 per sq yd

Calculation of standard deviation and construction of a bar chart showed that the process was depositing $12,000 to $20,000 worth of excess latex per month. Visual examination of the recorder charts revealed a definite machine-direction variation of latex coating and two cyclic variations—one caused by an out-of-round kiss-roll and another by the rug loom.

Earning Index

An increase in machine speed of 1 percent, quite practical after narrowing weight spread and reducing the target weight with fully automatic sizing-weight control, would mean an increment in profit margin of 2.5×10^6 sq yds per year x $3 per sq yd margin x 0.01 =

$75,000 per year

Reduction of deviations in the machine direction and reduction of target weight could easily reduce the overweight sizing by 50 percent (overweight film was practically eliminated in Case History I). This modest halving of overweight sizing would mean a saving in latex of

$12,000 to $20,000 per month x 12 months x $\frac{1}{2}$ =
$90,000 per year, a 9 percent saving in latex cost.

Initial cost of the measurement and control system would be:

1. System	$50,000
2. Delivery, installation, and calibration	2,000
3. Process modification	5,000
Total	$57,000

Annual maintenance charges would run to $2,000 per year, and straight-line depreciation of the initial cost to $11,400 per year. Then the net annual return on the investment could be $75,000 + $90,000 − $2,000 − $11,400, or $151,600 for an annual cost of $13,400. Put another way, this system would pay for itself in five months. Its earning index is 11.3.

CASE HISTORY III

Floor-tile calender—time and material savings

Figure 3 shows the basis weight measuring head installation. No deviation measurements were taken, but economic data was gathered.

Economic Model

1. Cost (labor, overhead, etc.) to operate calender, $120 per hour
2. Six gage changes per day in a 250-day operating year
3. Material cost, 5 cents per lb (including vinyl); 350 lb per batch; 600 batches per day = $10,500 per day

Commercial tolerance limits were plus and minus 4 percent. Experience gained in using the basis-weight measuring and control apparatus proposed here on other calendering processes pointed to a 50 percent narrowing of the tolerance limits. This, in turn, meant that the target could be reduced 2 percent without producing product any lighter than the original lower tolerance limit.

Earning Index

Operating cost savings from reducing gage-change time by 5 min:

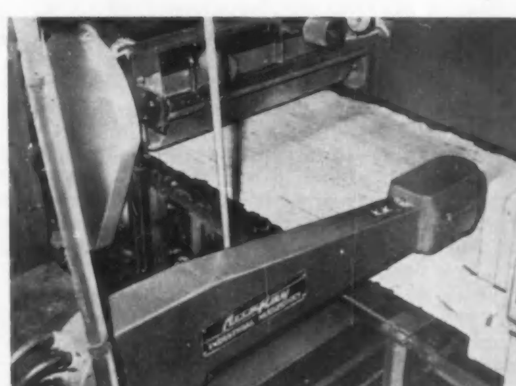
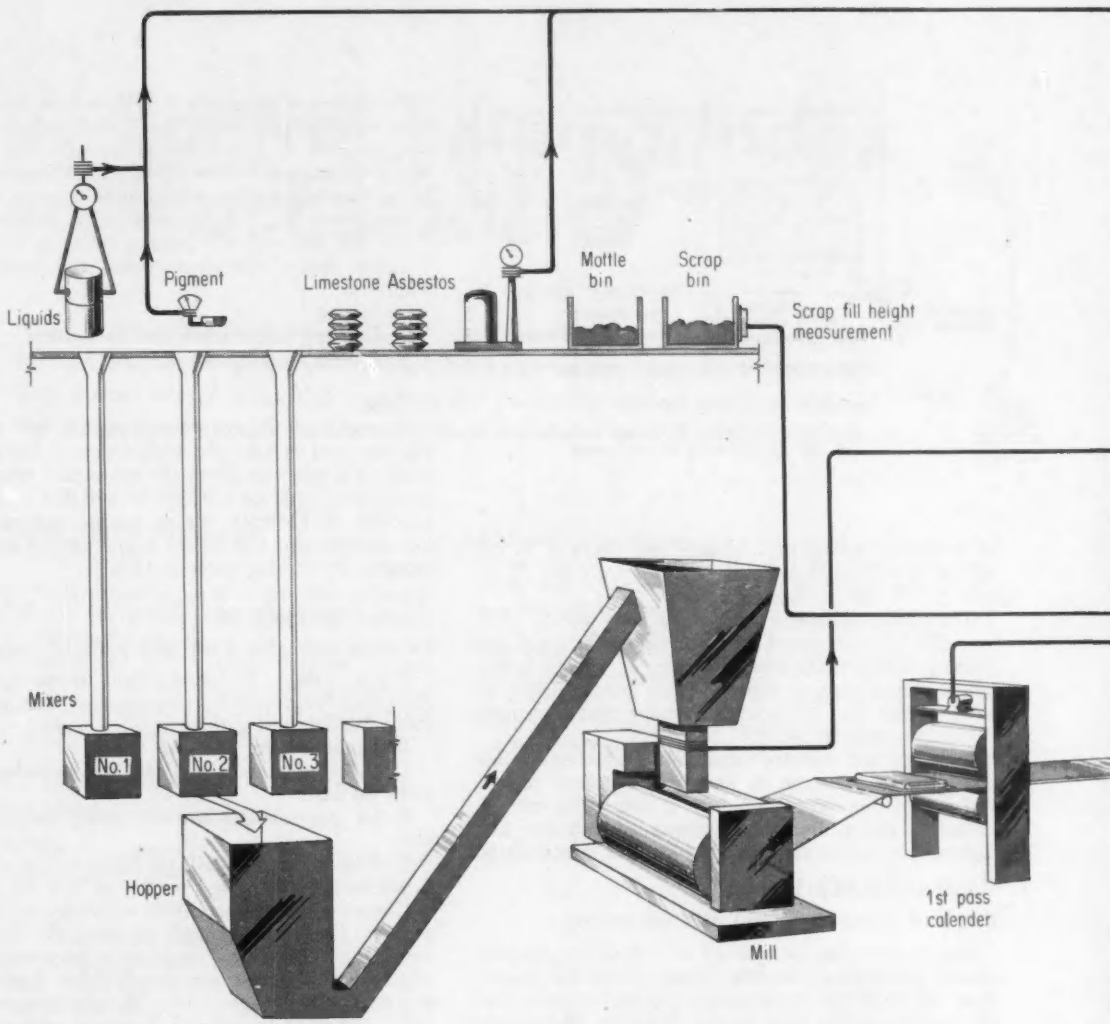


FIG. 3. Installation of basis-weight measuring head on floor-tile calender.



Six changes per day x 250 days x \$120 per hour operating cost x 1/12 hour reduction in gage-change time = \$15,000 per year.

Material savings:

\$10,500 per day material cost x 250 operating days x 2 percent target reduction = \$52,500 per year

Total = \$67,500 per year

Since annual depreciation and maintenance charges on the system would total about \$6,400, the earning index is (\$67,500 − \$6,400)/\$6,400 = 14.5.

Figure 4 shows the floor tile production line and the complete data acquisition and control system. The earning index given applies only to the gage-data acquisition and control system and not to the punch press and packing machinery. The system gathers and types out data on the entire operation, including raw materials, final product rate and quality, and scrap rate. Figure 5 demonstrates the form and volume of data typed on the production record. Figure 6 is a photograph of the latest data and control center.

To know how his design and estimates worked out, the control engineer must follow the application from his desk to its final acceptance and present a report that clearly interprets the technical results attained and thoroughly compares the economic results with those estimated. As in the pre-installation evaluation, calculation of standard deviation and plotting of statistical deviation charts are the best ways to gather the necessary information into a meaningful package.

If the measurement and control system specified includes an automatic production analyzer, the typed record will have an automatically computed analysis of product quality variance. From the variance the control engineer can prepare a plot of statistical deviation. Except for raw material costs, the typed record contains all the information he will need to run a post-installation calculation of the system's earning index.

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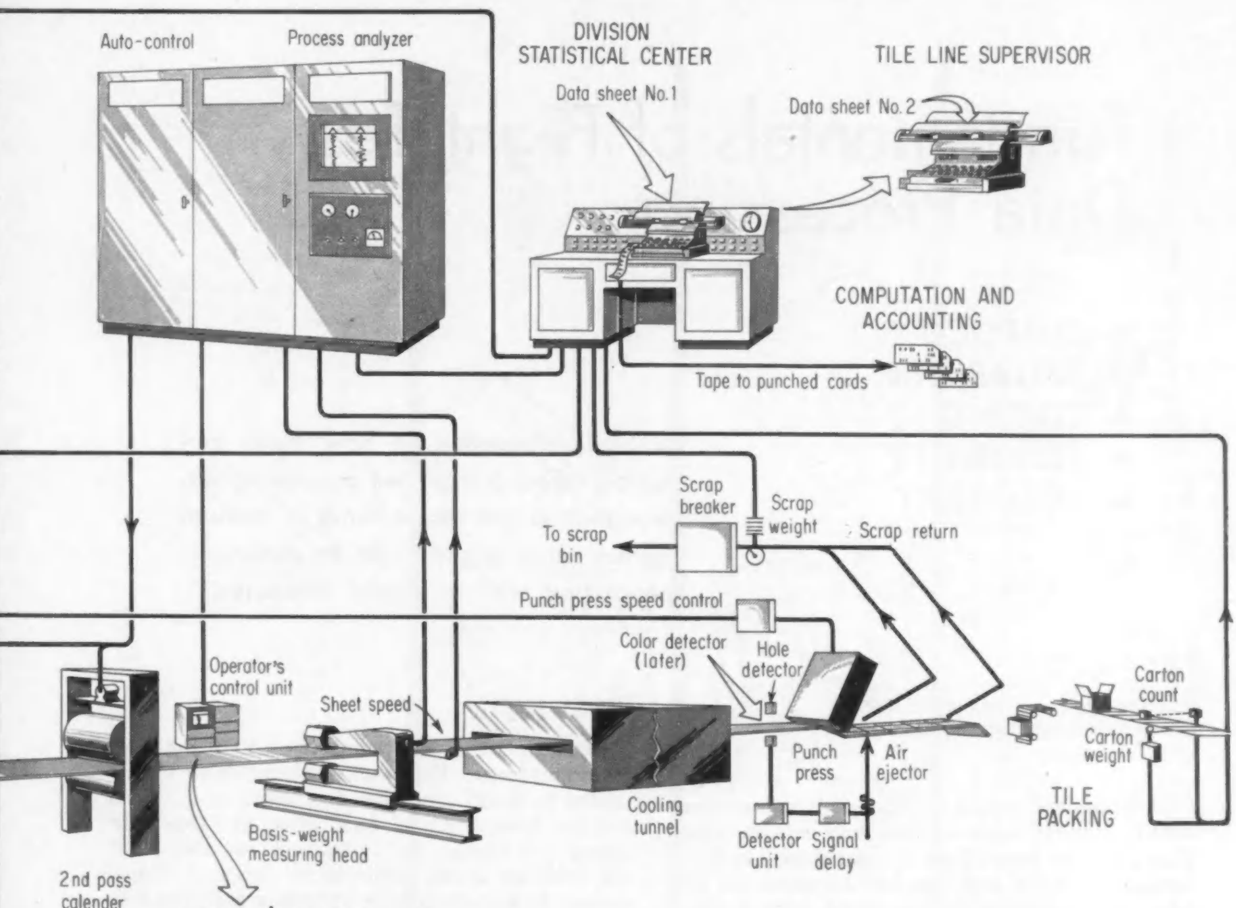
3. *USE RADIOACTIVE INSTRUMENTS*, P. J. Stewart and G. J. Leighton, March 1955, pp. 50-56.



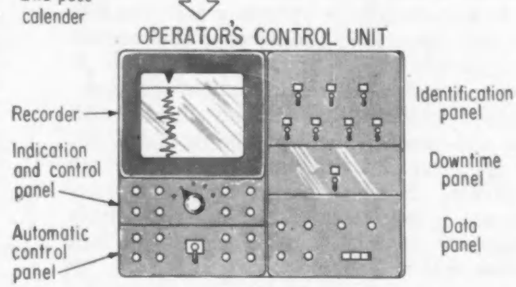


FIG. 4. Complete system will analyze and control floor-tile process, from proportioning of the raw materials to packing of the tiles in shipping cartons.

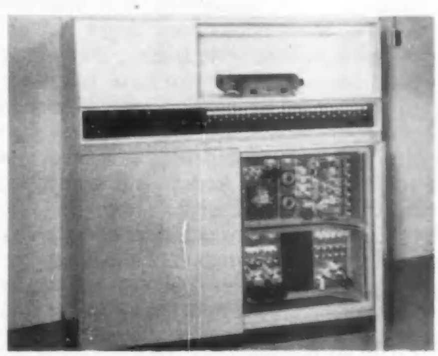


FIG. 6. Latest center analyzes and controls production quality.

ADACS PRODUCTION RECORD

DATE: OCT. 1, 1957
TIME: 0800

PLANT-1 NEWBURGH, NEW YORK

IDENTIFICATION				RAW MATERIAL INPUT														SCRAP			FINAL PRODUCT									
TIME	LINE NO.	OPER NO.	CODE NO.	LIMESTONE	ASBESTOS	WETT-AGENT	STABILIZER	PLASTICIZER	PIGMENT	CONTROL RESINS	VINYL RESINS	BINDER	MOTTLE	CHIPS	ACTUAL TONS	GOAL TONS	%	ACTUAL SCRAP	GOAL SCRAP	%	NO. OF CARTONS	SQ FT	ACTUAL TONS	GOAL TONS	%	TARGET WT	MEAN WT	VARIANCE	RUN TIME	DOWN TIME
0900	1	307	15117	621	200	24	50	30	45	25	33	34	–	33	895	900	99	390	390	100	360	162	900	900	100	116	116	20	60	0
				621	200	24	50	30	45	25	33	34	–	33	895	900	99	390	390	100	360	162	900	900	100					
	2	492	17195	505	160	15	15	15	15	10	5	4	6	–	750	800	94	330	330	100	300	135	750	800	94	114	115	16	60	0
				505	160	15	15	15	15	10	5	4	6	–	750	800	94	330	330	100	300	135	750	800	94					
	3	701	1911,2	485	195	30	25	5	20	25	15	–	10	–	810	800	101	375	330	113	300	135	750	800	94	114	114	10	60	0
				485	195	30	25	5	20	25	15	–	10	–	810	800	101	375	330	113	300	135	750	800	94					
1000	1	307	15117	621	210	14	55	25	45	25	34	33	–	33	870	900	97	370	390	95	320	150	810	900	90	116	116	10	55	5
				1242	410	38	105	55	90	50	67	67	–	66	1765	1800	98	760	780	97	680	312	1710	1800	95					
	2	492	17195	505	170	25	5	5	15	10	5	6	4	–	750	800	94	330	330	100	300	135	750	800	94	114	115	20	60	0
				1010	330	40	20	20	30	20	10	10	10	–	1500	1600	94	660	660	100	600	270	1500	1600	94					

FIG. 5. Portion of production analysis record printed by data acquisition and control system for floor-tile production.

Fundamentals of Flight Test Data Processing

- *SIMPLICITY*
- *RELIABILITY*
- *EDITING*
- *FLEXIBILITY*
- *ECONOMY*

A basic discussion of how these key factors affect a flight test processing system that might range from a manual system using a slide rule to automatic processing with a digital computer.

HELEN HEWITT and RALPH H. TRIPP
Grumman Aircraft Engineering Corp.

Choosing the proper flight test data processing system requires careful study and consideration. That's because there's been a major change in flight testing techniques over the past 15 years. In this field, data processing has developed from a visual reading, hand recording, and manual-calculation method using a few basic flight instruments, to a complex automatic recording, computing and presentation using many intricate transducers. Photo-panels, recording oscillographs, high-speed cameras, telemetry systems and tape recorders have supplanted the knee pad and pencil. On the ground, semi-automatic record readers, automatic plotters, electronic analog and digital computers are replacing the slide rule and mechanical desk calculator.

Most sophisticated data processing methods are the result of two developments. First, the airplanes are more complex and require more detailed information to evaluate characteristics and/or deficiencies. Second, the development of improved data handling equipment has enabled the engineer to make more detailed investigations with the collected data than was previously practical.

Because of the potential time and expense involved in modern information handling, extra care must be exercised in the planning and operation of the flight test data facility. The complexity dictates the use of the systems engineering approach. Basic requirements and considerations for the data system should be established before determining the specific hardware and methods to be used. Key considerations are: simplicity, reliability, editing, flexibility, and economy.

SIMPLICITY

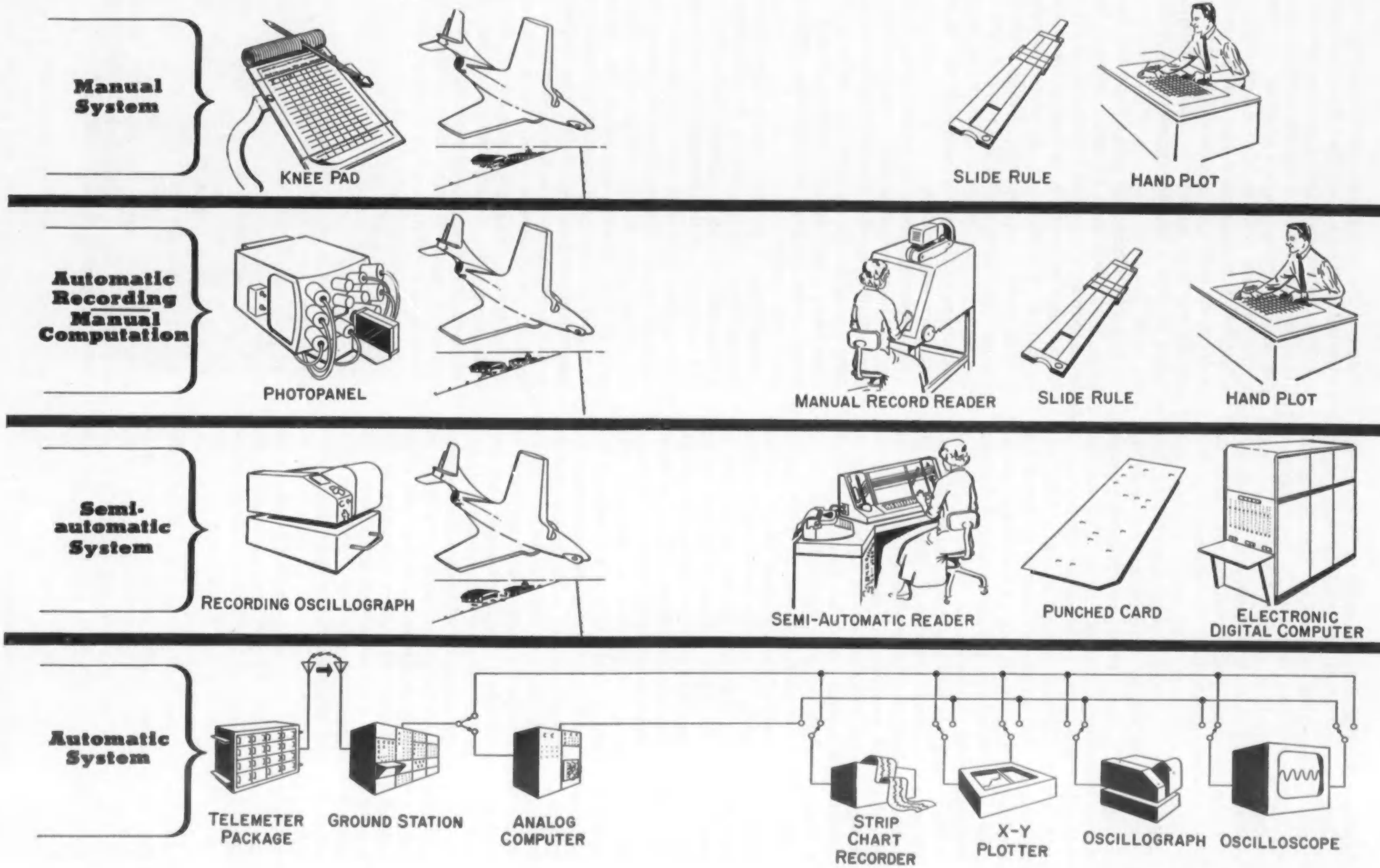
From a practical viewpoint, simplicity is the most important factor. The other requirements are closely related to it and somewhat dependent on it. Data systems have a strong inclination to "grow like Topsy". Although the instrument engineer starts out with an initial objective to design a simple system, he frequently ends up with a final result so complex that operations, bookkeeping and maintenance are overwhelming. And, the data suffers. It is a common failing to over-instrument and over-complicate a potentially simple installation. All kneepads and pencils should not be discarded just because telemetry and airborne tape recorders can be substituted. In many cases, making a measurement system fully automatic, and using extremely high frequency and high capacity equipment lead to excessive expense and excessive trouble.

It sometimes is difficult to drop the philosophy that equipment must be capable of a great deal more than it has to do because such performance might be needed in the future. There have been cases in which the data processing system was so jammed with things that might be used, that it was no longer suitable for its intended functions.

RELIABILITY

Hand in hand with simplicity goes reliability. Reliability has to be an objective in all facets of aircraft testing. The life of the pilot, the preservation of the airplane, the progress of tests, and the reputation of the manufacturer are all dependent on the reliability of measurements being made. From the data handling viewpoint, equipment reliability helps strengthen good working relationships with the design and test engineers who are inveterate

DATA HANDLING SYSTEMS



skeptics with respect to data from instrumentation.

There are two kinds of nonreliability. One is complete equipment component breakdown; the other, more insidious, occurs when the equipment appears to be working correctly but yields incorrect answers. Component breakdown can be kept to a minimum by using quality components within the limits of their capabilities. Even more important is keeping to a minimum the number of components whose failure can cause a permanent loss of data. This is the philosophy that dictates the recording of "raw data". For example, in a telemeter ground station the mixed RF carrier is recorded on tape, rather than the output of subcarrier discriminators, or scaled and zeroed voltage analogs. The malfunction of a subcarrier discriminator or operational amplifier then results in only a temporary unavailability of data, which may be recovered during a subsequent tape playback.

The second type of failures can be caused by system zero drift, sensitivity changes, faulty or insufficient calibration, or programming deficiencies. System drift and sensitivity changes can usually be monitored and compensated for by checking the measurement against a known value periodically throughout a test.

An example of this procedure is the so-called resistance calibration of a strain gage bridge. A fixed resistance, installed across one arm of the bridge, is calibrated before flight to obtain a relationship between it and the item measured. This relationship is called an "equivalent value". Here's how it works when the unknown is stick force. The fixed resistance might cause a measurement that is the same as that caused by a 50-lb pressure on the stick. The equivalent value is then 50 lb. This relationship is the norm to which other test measurements are referenced. If this resistance calibration is inserted at the transducer (the input of the data system), it should pass through the entire handling process of transmission, recording, computation and final presentations with the test data. If system sensitivity has changed, the output of this standard will change and supply a basis for compensation. In linear systems, a two-point resistance calibration will supply sufficient information. However, a multipoint calibration can be used in nonlinear systems. The necessity for periodic monitoring of each data channel during tests, especially during flight tests, should not be ignored.

One other piece of information which often needs to be monitored during tests is a reference location. Consider the whole system as a floating phenomenon. The differences can be detected quite accurately—using the resistance calibration, the sensitivity watchdog—but not the baseline, which is indefinite. For example, take rudder position. It is easy to determine how many degrees the rudder has moved; but it is not so easy to determine where the movement started. To pin down the absolute position relative to the vertical fin, a small wiper is attached to the rudder in such a way that at a specific position it makes contact with a wire inserting resistance in the measuring circuit. A significant interruption of the measurement occurs, one which can be identified as the reference position. This is commonly called a "diddle". Everytime the rudder is at this particular position, the diddle will appear and the data handler can identify it as the specific rudder position. The diddle supplies a base-line reference repeatedly during flight.

These two checks built into a flight test measurement system will tend to assure system reliability for everything except the transducer. If the transducer makes an error, the sensitivity check will not indicate it. Therefore, the transducer becomes the weakest point in the system. Environmental testing and meticulous pre-flight calibration are necessary to insure its reliability. Transducers should be checked under the conditions which will be present during the measurement.

Environmental testing encompasses checks at various combinations of altitude, temperature, static accelerations, humidity and dust conditions. Transducers should also be checked under applicable shock and vibration. Calibrations should be repeated under identical environmental conditions to check consistency.

Installation of the transducer is important, too; the instrument should measure the phenomenon it is supposed to measure. For instance, the location and alignment of the transducer is extremely important when measuring normal acceleration of the center of gravity. The instrument should be located on primary structure in such a manner that it is subjected to airplane acceleration as opposed to local accelerations. A transducer measuring control surface position must be installed so that it measures surface position under a loaded condition. If the transducer is attached to a component of the control linkage system, the linkage is evaluated and tested under conditions of flight loading to insure the relationship between ground and flight calibration. Reliability must be evaluated constantly: when planning an installation, while running the test, and in processing the data.

EDITING

Another basic requirement is the editing facility. Frequently only 5 to 10 percent of the total data recorded warrants detailed analysis. It is important to eliminate the extraneous information so the analyst is not required to work through stacks of papers to find the meaty portions. Early rapid editing reduces the work load of engineers, limiting their analyses to significant data.

The use of photopanels, oscillographs, and similar airborne recording systems postpones the editing until after a flight. Records must be developed, identified, scaled, and analyzed. This means hours

or perhaps days before the answers from a flight are known. Editing methods are much faster using automatic digital data reduction systems, which are applied to data recorded on airborne magnetic tape. But automatic systems are very costly and complex, introduce tougher operational and maintenance problems.

There is a compromise method which is immediate and fast. It can be performed using readily available and relatively inexpensive equipment. This technique is the in-line monitoring of telemetered data. Engineers can watch the outputs of key transducers while the test is in progress, making notations of flight sequences that require further analysis.

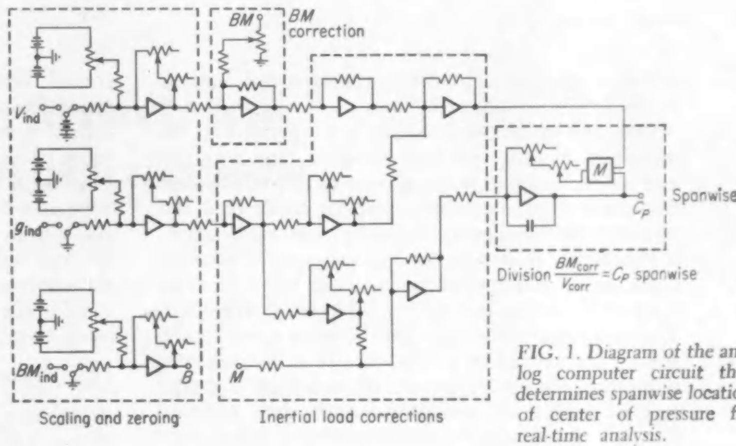


FIG. 1. Diagram of the analog computer circuit that determines spanwise location of center of pressure for real-time analysis.

And, to this monitoring function has been added a recent and advanced procedure: making available real-time, in-line, analog computations. In this new method the outputs of several transducers are processed by an analog computer that presents, while the test is in progress, neatly calculated data for the engineer to evaluate. He can then determine whether required flight conditions have been met and detect the approach to unsafe flight conditions. The engineer actually analyzes data during flight. This can mean a major saving in time and money. Using this technique the test program may not have to be stopped while data is analyzed.

In a test of wing performance, for example, the stress engineer can have displayed before him the wing center of pressure location while the flight is in progress as well as variables such as wing bending moment, torsion, shear, and acceleration. Thus, he watches the computed data in a form familiar to him and he can intelligently analyze the progress of the tests.

Figure 1 is a diagram of the analog computer circuit used at Grumman to determine the spanwise location of center of pressure. The telemetered analogs of wing shear, normal acceleration, and wing bending moment are inputs to the analog computer. First, all voltages are zeroed and scaled suitable for machine operation. (Indicated shear is corrected for bending and inertial loads to compute total airload shear; indicated bending moment has an inertial load correction applied to compute total airload bending moment; normal acceleration is used to determine the proper inertial load corrections.) Then, a multiplier is used inversely to divide the total bending moment by the total shear; this gives the spanwise location of center of pressure as an output. Similarly, the chordwise location is calculated using total torsion and total shear computations. The two outputs of the analog computer drive the x and y axes of a large scale oscilloscope with a wing planform overlay, scaled to be consistent with the computed data (Figure 2).

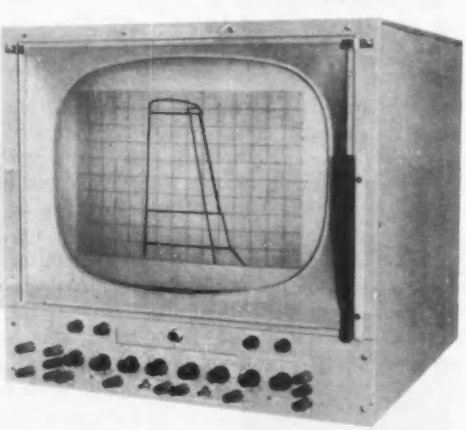


FIG. 2. Two outputs of the analog computer drive the x and y axis of 21 in. oscilloscope with a wing planform overlay to speed decision-making during a test.

Other real-time computations which have been performed are automatic plotting of stick force vs. g, pitching moment vs g, and yawing moment vs. yaw angle. Pressure coefficients have been calculated from pressure profiles and displacements have been integrated from velocity pickups. Lift coefficient, pitching moment coefficient, true Mach number, specific range and temperature distributions—just a few examples of a unlimited number of real time analog presentations that are feasible—can all be computed and displayed in real time to enable engineers to make immediate analyses.

The equipment necessary to process analog data in real time is generally neither expensive nor complex by comparison to some of the automatic digital-data systems. And its use results in a tremendous time saving and subsequent cost reduction. It can also be used for post-flight computations of tape recorded data to expedite data editing and analysis.

FLEXIBILITY

Flexibility is another basic requirement of the data processing system. In a flexible system, recording and computing components are interchangeable and use both analog and digital methods. A flexible system

will have a high potential for expansion and development as the job changes.

One way to achieve flexibility is to specify that the recording oscillograph, the airborne tape recorder, and telemeter package are all able to record the same transducers. An installation can be made in a test aircraft with transducers recording on an oscillograph, for example. If, during the test program, it becomes desirable to monitor certain of these transducers on telemetry, all that is required is to change recorders. The resistance calibration has the same value regardless of the recording media, resulting in consistent equivalent values. The data recorded on airborne magnetic tape is compatible with data received through telemetry; identical analog computation methods can be applied for post-flight data analysis and in-line data analysis.

It is more difficult to achieve compatibility between analog and digital parts of the system. To take full advantage of the ability to see answers in analog form and to take full advantage of the high speed and high precision of digital computers, an efficient conversion system is required. Most data chains have manual or black box links which convert from analog to digital or from digital to analog. However, these are often limiting time-wise. There is an abundance of digital and analog equipment, but conversion systems generally need further development to fuse the two without incurring a time sacrifice.

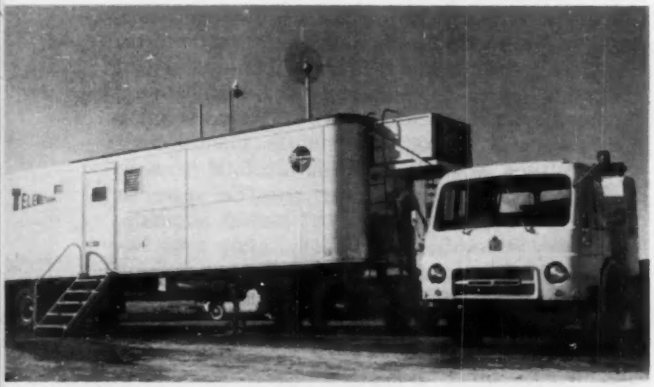


FIG. 3. Mobile data system mounted in van is capable of in-flight monitoring and computing to make answers available during flight.

Data systems are all expandable. Additional computers, plotters, tape recorders, etc., can be added as required. Some systems are designed to be complete for all present and all anticipated needs. On the other hand, the system can be designed for minimum operation, to have a nucleus of essential equipment whose capabilities and complexities can be increased as the need arises.

If a system is expandable, the education of personnel, both analysis and instrumentation, can be more gradual and thorough. They can start with a simple system and grow with it. Data analysts are more prone to accept new methods if they can participate in their development. And instrumentation engineers obtain a better understanding of problems and system requirements when an expandable design concept is used. Because data handling methods and the hardware to implement them are changing quite rapidly, the systems engineer must try to retain flexibility to expand in any of several directions.

ECONOMY

Probably the most controversial factor in flight testing today is accuracy. A careful evaluation of practical accuracy can result in a great saving. It is a common mistake to carry out computations to an undue number of significant digits. These computations are beyond the accuracy attainable or the accuracy required. An excess number of significant digits does not contribute to the accuracy or reliability of a system: they just add to the cost. In a system, limited by 1 percent transducers, it is meaningless to compute data to 10 significant figures.

Time saving is usually dollar saving. The quicker the answer is available, the less expensive is the test. One way that answers have been made available immediately, regardless of the test site, is through the use of a mobile data system which is mounted in a 35-foot semitrailer. This unit is self-powered by a 50-kw gasoline-driven generator, so it may be operated from any test location. It is equipped with a complete FM-FM ground station, an analog computer and oscilloscope, pen recorder, x-y recorder, and oscillographic readouts. This van is capable of both in-flight monitoring and computing, so that it makes answers available during flight. It must be remembered that a flight test data system is after answers, not a pile of data. Perhaps, if it were called a Flight Test Answer System, efforts would be directed to that end and economy achieved. This economic analysis need not be confined to massive expenditure. Rather, it should be applied carefully down the line to all equipment and balanced against the other requirements of simplicity, reliability, editing facility, and flexibility.

WHAT'S NEEDED

Flight test data processing is still far from a cut-and-try process. Several new developments are urgently needed. Equipment and techniques which need to be perfected to facilitate and speed up data processing fall into two categories: better digital to analog and analog to digital conversion equipment so that the advantages of each may be utilized fully, and better real-time analysis equipment which will present answers instead of data, thus saving much valuable time and effort. Although testing has progressed a long way from the kneepad and pencil, new systems will still have to be competitive.

Comparison Chart for Passive Demodulators

BENJAMIN BARRON, Magnetic Amplifiers, Inc.

Demodulators convert ac signals into dc. They differ from ordinary rectifiers in that they preserve the phase sense of the ac input as the polarity of the dc output. There are many ways to demodulate signals; among them: electromechanical choppers, vacuum-tube and transistor amplifying demodulators, and completely passive demodulators that use transformers, resistors, and diodes. Only passive demodulators are discussed here. These resolve themselves into two basic groups; the "sum and difference" types of Figures 1 and 2, and the "synchronous switching" types of Figures 3 and 4. The first operates by summing the signal with a reference voltage, the second by timing the passage of signal current through biased diodes. The chart on the next page lists the characteristics of the four push-pull circuits in Figures 1 through 4. These circuits afford the highest signal conversion efficiencies for their types and are inherently balanced. The single-ended counterparts of these push-pull circuits are considered of little practical importance. Good audio transformers must be used; the center-taps must be electrically centered both in magnitude and phase. Diode choice depends on the carrier frequency and the accuracy required. Selenium diodes are limited to frequencies below about 800 cps.

Sum and Difference Demodulators

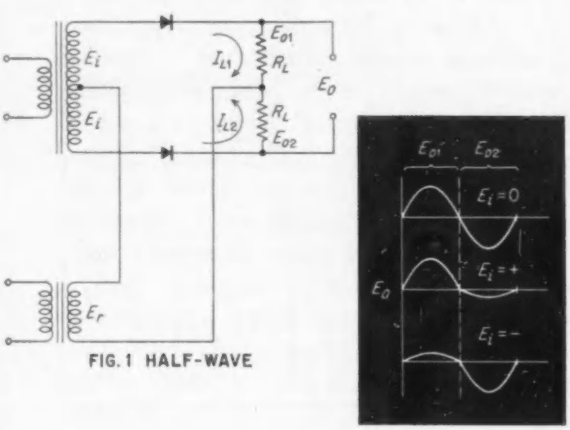


FIG. 1 HALF-WAVE

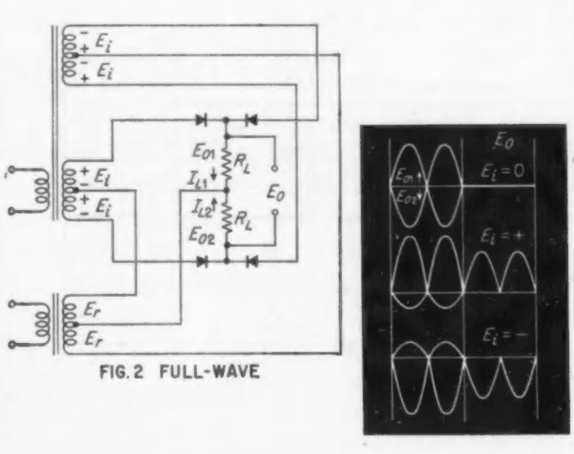


FIG. 2 FULL-WAVE

Synchronous Switching Demodulators

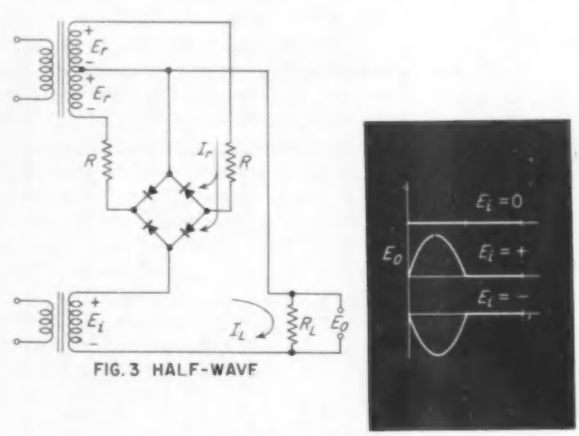


FIG. 3 HALF-WAVE

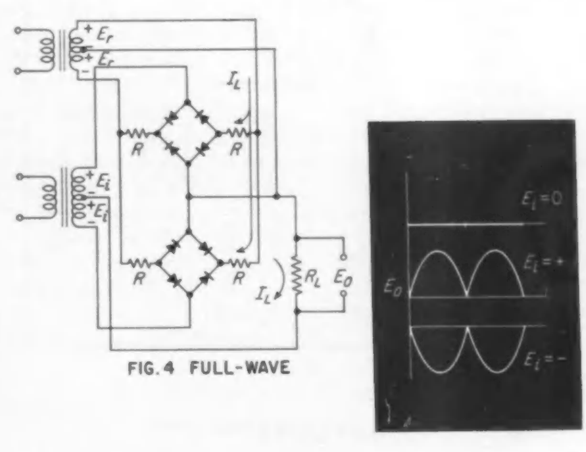


FIG. 4 FULL-WAVE

CHARACTERISTICS OF PASSIVE DEMODULATORS

Type	Operation	Load	Factors Affecting Fundamental Balance Sensitivity	Approximate Balance Accuracy with No Adjustment, volts: Selenium Diodes	Germanium Diodes	Silicon Diodes	Output Current (dc), amps; and Signal Conversion Efficiency, percent
Sum and Difference	Half-wave (Figure 1)	Split	• Load matching • Diode forward drop matching • Forward to back resistance ratio of diodes	$\frac{E_{ref}}{5} \times 0.30$	$\frac{E_{ref}}{5} \times 0.15$	$\frac{E_{ref}}{5} \times 0.050$	Differential current: $\Delta I_{dc} = \frac{0.90E_i}{R_L}$ Efficiency = 20.3 at $E_i = E_r$
	Full-wave (Figure 2)	Split	• Load matching • Diode forward drop matching • Forward to back resistance ratio of diodes	$\frac{E_{ref}}{5} \times 0.10$	$\frac{E_{ref}}{5} \times 0.030$	$\frac{E_{ref}}{5} \times 0.010$	Differential current: $\Delta I_{dc} = \frac{1.80E_i}{R_L}$ Efficiency = 81 at $E_i = E_r$
Synchronous Switching	Half-wave (Figure 3)	Single-ended	• Diode forward drop matching • Forward to back resistance ratio of diodes	0.30	0.15	0.050	Current: $I_{dc} = \frac{0.45E_i}{R_L}$ Efficiency = 20.3
	Full-wave (Figure 4)	Single-ended	• Diode forward drop matching • Forward to back resistance ratio of diodes	0.10	0.030	0.010	Current: $I_{dc} = \frac{0.90E_i}{R_L}$ Efficiency = 81

Type	Operation	Basic Differential Null Voltage	Ripple Voltage in Dc Output, percent	System Constants E_{ref} and R	Reference Power; Based on Maximum Output Power	Application Remarks
Sum and Difference (continued)	Half-wave (Figure 1)	E_r	$E_{01} - E_{02} = 121 \times \frac{E_r}{E_i}$ (at carrier frequency)	Given R_L, ΔI_{dc}: $E_{ref} = \frac{\lvert\Delta I_{dc}\rvert R_L}{0.90}$	$1.24 P_{out(max)}$	• Simplest circuit into split load • Low signal conversion efficiency and large ac ripple at null tolerable • If filtering is required, carrier frequency should be greater than 40 times system natural frequency
	Full-wave (Figure 2)	0	$E_{01} - E_{02} = 48$ (at twice carrier frequency)	Given R_L, ΔI_{dc}: $E_{ref} = \frac{\lvert\Delta I_{dc}\rvert R_L}{1.80}$	$0.618 P_{out(max)}$	• Split loads with ampere-turn sensitivity such as torque motors, magnetic amplifier control windings, hydraulic valve solenoids, dc motor fields • Best application where limited reference power available
Synchronous Switching (continued)	Half-wave (Figure 3)	0	121 (at carrier frequency)	Given R_L, I_{dc}: $E_{ref} = \frac{\lvert I_{dc}\rvert \times R_L}{0.45}$ $R = R_L$	$4.94 P_{out(max)}$	• No input transformer required • Low signal conversion efficiency and ac ripple content tolerable • Low noise phase angle measuring systems • Unlimited reference power available
	Full-wave (Figure 4)	0	48 (at twice carrier frequency)	Given R_L, I_{dc}: $E_{ref} = \frac{\lvert I_{dc}\rvert \times R_L}{0.45}$ $R = 2R_L$	$4.95 P_{out(max)}$	• Demodulator where network functions must be performed • Efficient signal converter into single load where ripple and filtering must be minimized • Phase angle measuring systems with distortion present in input signal • Unlimited reference power available

The Noninteracting Controller for a steam-generating system

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A. LEE, Bureau of Ships, U. S. Navy

THE GIST: Steam-generating boilers aboard Navy combat vessels provide motive power for propulsion and maneuvering, and sometimes steam for catapulting aircraft into flight. Such boilers must change from 10-percent to 90-percent load in less than 45 sec and deliver steam to catapults in half that time. These rapid changes in demand and firing impose severe excursions in temperature and thermal strain on boiler parts. Maintaining water level, one of the major boiler-control problems, depends on such boiler design considerations as the configuration of heat-transfer surfaces, water circulation pattern, and rate of feeding fuel and water. In addition to boiler design, location of instruments and the combustion control scheme used determine boiler controllability.

Past experience and new demands indicate the need to ease off on overextended components, to get certain boiler parts to respond faster, and to simplify controls. These needs are being investigated for the Navy by Beckman/Systems Div. The dynamic analysis of the boiler was completed and reported in detail at the ASME IRD Conference on Automatic Optimization (ASME Paper 58-IRD-7). This article reviews the boiler analysis and then goes beyond it, revealing the design of a noninteracting controller to improve boiler performance by limiting unwanted excursions of variables.

• •

In conventional control, a change must occur at a variable before corrective action can be taken to bring the variable back to its desired value. This is quite satisfactory for systems in which each variable is essentially independent of others. But such is not the case for steam-generating boilers. Here, interactions between input and output variables during corrective action for one input upset all output variables. For instance, a change in steam flow rate affects drum-water level and pressure. Then, corrective action in feed-water rate—to bring water level back to normal— also affects pressure, which will have to be corrected by adjusting fuel rate. Such interaction limits boiler controllability when using conventional proportional plus reset control modes.

The need for improved boiler control is an accepted fact, in view of such existing control problems as shrink and swell in the drum, fluctuations in drum pressure with changes in load, and optimization of the air-fuel ratio for maximum efficiency at different loads. The systems approach provides a way to eliminate these problems, by giving a better understanding of the boiler operation. Then, the designer has a chance to improve on the boiler itself, to make it more susceptive to control by design of new control schemes, and to optimize performance.

The systems approach consists of three steps:

► Analyzing the boiler by phenomenological description, mathematical formulation, and solution in terms of transfer functions.

► Synthesizing a new control system from the derived boiler transfer functions.

► Evaluating the overall system both theoretically and experimentally, thereby justifying assumptions made during the analysis and seeing that the synthesis fulfills system requirements and expectations.

The major drawback in boiler control studies is that the mathematical description of the whole system is very complex, containing numerous nonlinear variables and uncertainties in some physical phenomena. Simplifying assumptions must be made to facilitate problem solution. But oversimplification results in solutions that do not describe dynamic behavior properly. Simplifying assumptions are of two types:

1. Simplification of certain physical phenomena too complex to admit an exact mathematical descrip-

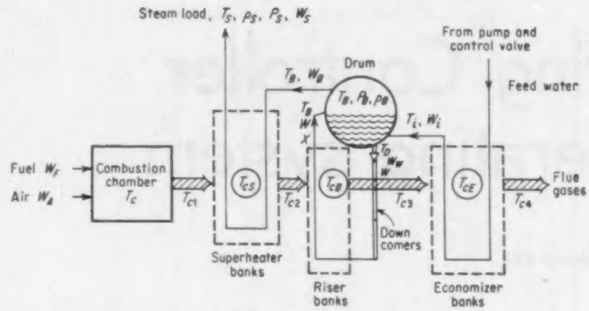


FIG. 1. Simplified boiler diagram.

tion. Examples of such phenomena are heat transfer equations in nucleate boiling, evaporation or condensation rates in the drum, and turbulent heat transfer from hot combustion gases to tube walls. Some semi-empirical or approximate equation is required.

2. Simplification of equations, either exact or approximate, to eliminate nonlinearities. Partial differentation through difference-equation or numerical-analysis methods yields a set of linear ordinary differential equations for the dynamic behavior of the boiler, but these equations are too formidable for hand solution, even for one steady-state condition (each steady-state condition introduces new coefficients of variables). For this reason, machine computation must be used.

Figure 1, a simplified boiler diagram, shows that the boiler dynamics can be analyzed in four sections: superheater, downcomer-riser loop, drum, and gas path. (A fifth section may describe the slow dynamic behavior of the air path—from input blower to top of stack—but, for sake of brevity, it will not be considered here.) With simplifying assumptions for this boiler in mind, four basic types of equations—flow, heat transfer, steam state, and rigid body motion—are derived or approximated empirically to describe boiler dynamics. The flow and heat transfer equations involve partial differentiation and contain nonlinearities, so that they must be linearized by perturbation and difference-equation techniques.

TABLE I—THE BOILER'S DYNAMIC EQUATIONS

SUPERHEATER BANK:

Figure 2 shows the superheater bank, which is considered as a single capacitance with one restriction at the entrance and another at the exit. Variables ρ_S, T_S, and P_S are taken lumped parameters, and thus in an actual case represent the superheater output density, temperature, and pressure. The length of the superheater tubes is taken as L_S and the total cross sectional flow area of the bank as A_S.

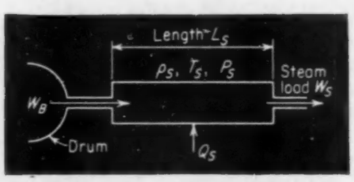


FIG. 2. Simplified single-section superheater.

Continuity equation:

$$w_B - w_S = \frac{d}{dt}(L_S A_S \rho_S)$$

$$= L_S A_S \frac{d\rho_S}{dt}; \text{ or in perturbed form} \quad (4A)$$

$$\Delta w_B - \Delta w_S = L_S A_S s \rho_S \quad (4B)$$

where d/dt is replaced by its equivalent Laplacian operator (s).

Momentum equation:

The superheater's inertial terms are assumed neglected, compared to frictional terms. The validity of this assumption can be shown both analytically and experimentally. Hence:

$$P_B - P_S = f_S(w_B^2/\rho_B) \quad (5A)$$

w_B is the steam-mass flow rate and ρ_B is the saturated steam density corresponding to drum pressure. Since the pressure drop across the superheater $(P_B - P_S)$ is known from steady-state conditions, the friction coefficient for Equation 5A can be calculated. Writing Equation 5A as a perturbation equation about its steady-state conditions:

$$\Delta P_B - \Delta P_S = 2f_S \frac{\bar{w}_B}{\bar{\rho}_B}\Delta w_B - f_S \frac{\bar{w}_B^2}{\bar{\rho}_B^2}\Delta \rho_B \quad (5B)$$

Bars (—) above the variables indicate steady-state values.

Energy equation:

$$Q_S + w_B h_B - w_S h_S = \frac{d}{dt}(A_S L_S \rho_S h_S) \text{ or } (6A)$$

$$\Delta Q_S = (A_S L_S \bar{\rho}_S s + \bar{w}_S) C_{PS}\, \Delta T_S + (\bar{h}_S - \bar{h}_B)\, \Delta w_B \quad (6B)$$

To get Equation 6B, the term $A_S L_S d\rho_S/dt$ is replaced by its equivalent from Equation 4A. It is also assumed that $\Delta h_B = 0$ and $\Delta h_S = C_{PS}\Delta T_S$ are valid for small variations about steady-state values.

Heat input to superheater:

The empirical equation for heat transfer rate into a turbulent gas flowing within a pipe is:

$$Q_S = k_S(w_B)^{0.8}(T_{wS} - T_S) \quad (7A)$$

where T_{wS} is the superheater wall temperature. k_S is again determined from steady-state conditions since Q_S, w_B, and T_S are known, and T_{wS} can be calculated. Hence:

$$\Delta Q_S = \frac{0.8 k_S}{(\bar{w}_B)^{0.2}}(\bar{T}_{wS} - \bar{T}_S)\, \Delta w_B + k_S(\bar{w}_B)^{0.8}(\Delta T_{wS} - \Delta T_S) \quad (7B)$$

If the heat input rate to the superheater walls from hot combustion gases is Q_{gS} then:

$$Q_{gS} - Q_S = M_S C_S \frac{dT_{wS}}{dt} \quad (8A)$$

where M_S is the total mass of the superheater tubes and C_S is its heat capacitance.

$$\Delta Q_{gS} - \Delta Q_S = M_S C_S s\, \Delta T_{wS} \quad (8B)$$

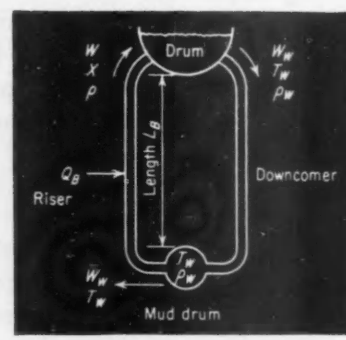


FIG. 3. Simplified downcomer-riser loop.

DOWNCOMER-RISER LOOP:

Figure 3 shows the simplified diagram of the downcomer-riser loop with the variables indicated along the path. The downcomer is assumed to have simple fluid flow character, with no heat input or temperature delays between the top and the bottom. However, entrance and exit head losses are taken into account, and the downcomer particularly is assumed to terminate at a mud drum to dissipate all available kinetic energy in turbulence.

Flow equations are similar to those for

Linearizing techniques

Suppose an equation of the form:

$$f\left(x,y,z,\ldots,\frac{\partial x}{\partial t},\frac{\partial x}{\partial l},\frac{\partial y}{\partial t},\frac{\partial y}{\partial l},\ldots\right)=0 \tag{1}$$

is to be reduced to linear ordinary differential equation form, where $\partial/\partial t$ indicates time derivative and $\partial/\partial l$ is the derivative with respect to the space variable l. For small space intervals L, variables x, y, z, . . . may be written as linear functions of the variable such that:

$$\frac{\partial x}{\partial l}=\frac{x_2-x_1}{L};\quad \frac{\partial y}{\partial l}=\frac{y_2-y_1}{L};\quad \frac{\partial z}{\partial l}=\frac{z_2-z_1}{L},\ldots$$

where x_2, y_2, z_2, and x_1, y_1, z_1, denote the value of the variables x, y, and z at the end and beginning of L.

Even though x_1, y_1, z_1, and x_2, y_2, z_2, are no longer functions of l, they are still functions of time. x, y, z, $\partial x/\partial t$, $\partial y/\partial t$, $\partial z/\partial t$, are now assumed to be the value of the variables at the beginning of the space interval L; hence, Equation 1 can be written as:

$$f\left(x_1,y_1,z_1,\ldots\frac{dx_1}{dt},\frac{x_2-x_1}{L},\frac{dy_1}{dt},\frac{y_2-y_1}{L},\ldots\right)=0 \tag{2}$$

Equation 2, then perturbed about its steady-state operating condition to eliminate the nonlinearities, can be written as:

$$\frac{\partial f}{\partial x_1}\Delta x_1+\frac{\partial f}{\partial y_1}\Delta y_1+\ldots$$

$$\frac{\partial f}{\partial x_2}\Delta x_2+\frac{\partial f}{\partial y_2}\Delta y_2+\frac{\partial f}{\partial\left(\frac{dx_1}{dt}\right)}\Delta\frac{dx_1}{dt}+\ldots=0 \tag{3}$$

where $\Delta\frac{dx_1}{dt},\Delta\frac{dy_1}{dt}\ldots$ can be replaced by

$\frac{d}{dt}(\Delta x_1),\frac{d}{dt}(\Delta y_1)\ldots$ for small perturbation.

It is seen from Equation 3 that time derivatives dx_1/dt, dy_1/dt, dz_1/dt are treated as independent variables, and second or higher order terms in perturbed variables are neglected. The partial differentials $\partial f/\partial x_1$, $\partial f/\partial x_2$, $\partial f/\partial y_1$, forming coefficients of the perturbed variables, are evaluated at the initial steady-state operating conditions about which the dynamic

the superheater, with the inclusion of the inertial terms. Density and the enthalpy in the riser is written in terms of the mixtures quality x.

Heat transfer from riser tube walls into boiling liquid is given by the equation:

$$Q_B=k_e(T_{wB}-T_B)^3 \tag{9A}$$

where k_e is determined from steady-state conditions and T_{wB} is the riser tube wall temperature. T_{wB} is a function of the heat flow rates into and out of the tube wall and is formed from an equation similar to 8B. Equation 9A may be written in the perturbed form as:

$$\Delta Q_B=3k_e(\overline{T}_{wB}-\overline{T}_B)^2(\Delta T_{wB}-\Delta T_B) \tag{9B}$$

DRUM:

Drum dynamic equations are derived by considering the mass and heat balances in the drum for both the vapor and the liquid phases. Figure 4, the drum diagram, shows various input and output variables. In this analysis the effect of mass and heat transport phenomena between the two phases are taken into consideration, but the water-level variation due to bubbles within the liquid is neglected.

Three drum equations are obtained in the following perturbed form after appropriate algebraic manipulations:

$$\begin{aligned}
&[\overline{M}s+\overline{W}_w+k_e(h_B-\overline{T}_w)]\,\Delta T_w\\
&\quad=(1-\bar{x})(T_B-T)\,\Delta w\\
&\quad+[(1-\bar{x})\bar{w}+k_e(h_B-\overline{T}_w)]\,\Delta T_B\\
&\quad-(\overline{T}_w-\overline{T}_i)\,\Delta w_i+\bar{w}_i\,\Delta T_i\\
&\quad-(\overline{T}_B-\overline{T}_w)\bar{w}\,\Delta x
\end{aligned} \tag{10}$$

$$\begin{aligned}
&\frac{\overline{V}_B}{r}s\,\Delta\rho_B+k_eT_B-\left(\frac{1-r}{r}+\bar{x}\right)\Delta w\\
&\quad+\frac{1-r}{r}\Delta w_w-\bar{w}\,\Delta x-k_e\,\Delta T_w\\
&\quad+\Delta w_B=\frac{1-r}{r}\Delta w_i
\end{aligned} \tag{11}$$

$$\begin{aligned}
\rho_w s\,\Delta y&=\Delta w_i+(1-\bar{x})\,\Delta w-\bar{w}\,\Delta x\\
&\quad-\Delta w_w-k_e(\Delta T_w-\Delta T_B)
\end{aligned} \tag{12}$$

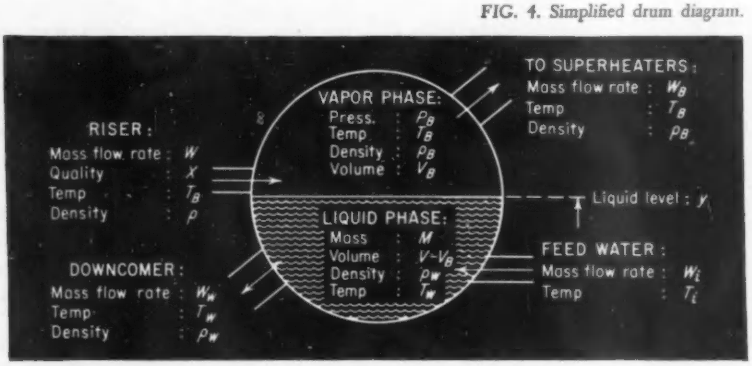
where $r=1-\rho_B/\rho_w$

State equations are obtained from steam tables and approximated as linear functions about a steady-state operation condition. Dynamic equations relating heat and mass transport phenomena between the hot combustion gases and various boiler components can be derived by considering the turbulent heat transfer equations (empirical equations) and the effect of the heat transfer to riser and superheater tubes on the average combustion gas temperature.

Heat transfer and frictional coefficients are determined from the unperturbed forms of the equations, by substituting the proper steady-state values of the variables. Similarly, steady-state values of the quality in the riser tube discharge and the circulation rate may be obtained by simultaneous solution of the unperturbed riser-downcomer loop equations. This simply means solving a third-order algebraic equation in quality x.

Determination of friction and heat-transfer coefficients and the steady-state values of the quality and circulation rate makes it possible to set up the boiler's complete dynamic equations. Some of the relations are simple enough to be eliminated by hand computation, so that the final set obtained for computer solution consists of 18 equations. These equations are not shown because their coefficient values apply specifically to the particular boiler under consideration.

FIG. 4. Simplified drum diagram.



behavior of the boiler is to be analyzed. As a result of these simplifications, Equation 3 becomes a linear first-order ordinary differential equation with constant coefficients in perturbed variables x_1, x_2, y_1, y_2...

The linearizing method will now be applied to the four boiler parts mentioned previously. In the initial analysis the space interval L is taken to represent the total length of the superheater and riser tube banks. In conjunction with the above method, this results in the smallest possible number of equations for the boiler. Typical nonlinear equations and their linearized form are shown in Table I.

Simulation simplifies analysis

The set of simultaneous dynamic equations (in Laplace transform form) obtained from analysis and linearization is solved on an analog (or digital) computer. Computer solution serves three distinct purposes:

- Finding open-loop transfer functions of variables
- Studying the effect of different types of control systems
- Checking the validity of basic assumptions

Open-loop transient response of such critical boiler variables as drum pressure, water level, and superheater outlet temperature with respect to steam flow rate, fuel flow rate, and feed-water flow rate, are obtained by computer simulation. Figure 5 shows the responses of drum pressure P_B to a step-change in feed-water rate (A), fuel rate (B), and steam flow rate (C). The variables for these curves are normalized such that ′ indicates percent change from the steady-state value of that particular variable. The response curves indicate that transfer functions P'_B/w'_i, P'_B/w'_F, and P'_B/w'_S can be approximated, with reasonable accuracy, by single time constants.

Figure 6 shows the transient response of water level y for a step change in feed-water rate (A), fuel rate (B), and steam-flow rate (C). Note that for a sudden change in the steam flow rate, the water level first goes up, then decreases at a more or less uniform rate. The swell observed here is the result of the sudden evaporation in the riser because of reduced drum pressure. It is similar to the swell observed in the boilers when there is a sudden increase in load, although as was mentioned before, the analysis does not include the effect of the bubble formation within the drum liquid. Hence, the set of equations developed will predict swell and shrink, but only qualitatively.

Figure 7 shows reasonable closed-loop responses of a simulated boiler with a simulated proportional and reset controller (such as is common in modern power plants) following optimal adjustment of the control parameters on the analog computer. The transient responses are of drum pressure, water level, feed-water rate, and fuel flow rate when there is a step change in the steam flow rate. Initial swell of the water level still exists, even though its amplitude is somewhat reduced by the controller.

The effect of various boiler (physical) dimensions on system dynamics can be found by changing appropriate settings of the computer's potentiometers and observing their effects on the boiler variables. It then becomes possible to investigate qualitatively the influence of drum size, the heat transfer surface area of riser and superheater, the length of tubes, and the mass of the tubes on the system's transient responses, and to determine some design rules for better dynamic behavior.

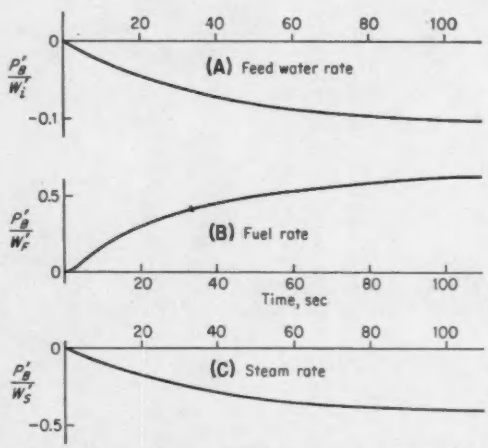


FIG. 5. Open-loop transient response of pressure with step-change in feed-water rate, fuel rate, and steam rate.

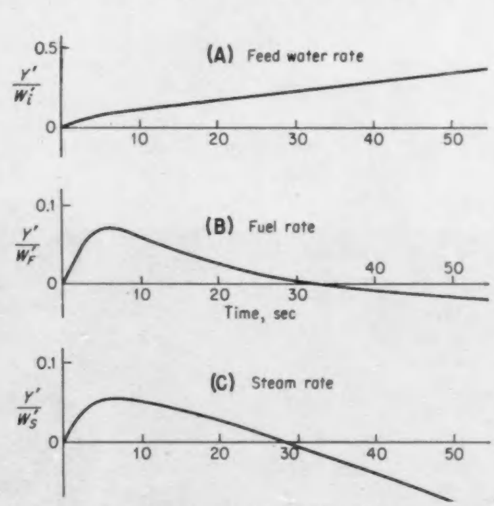


FIG. 6. Open-loop transient response of water level with step-change in feed-water rate, fuel rate, and steam rate.

The noninteracting controller

Once the basic limitations of the boiler itself are known, a controller that could at least partially overcome these limitations may be conceived. Since one of the major difficulties in boiler control is interaction between different input and output vari-

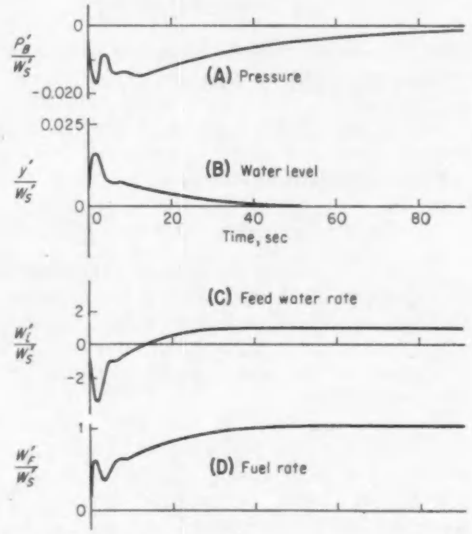


FIG. 7. Closed loop transient response (with a linear controller) of steam flow rate with a step-change in pressure, water level, feed-water rate, and fuel rate.

ables, a major objective of a new boiler-controller design was virtual elimination, or at least reduction, of the fluctuation in drum pressure and water level when steam flow rate changes.

Analysis and analog-computer experimentation show the feasibility of a boiler noninteracting controller that will automatically limit the interaction between input and output variables and improve the boiler response appreciably. In theory, it will be possible to increase the steam rate without any change in the drum pressure and water level; in practice, these fluctuations can be kept very much below their present values as obtained with proportional plus reset controllers.

In the following analysis it is assumed that the transfer functions for the boiler input-output variables are known; that is, the relations between steam, feed-water, and fuel rates (inputs), and drum pressure and water level (outputs) have known mathematical formulations. These relations as obtained in dynamic analysis are assumed to be exact for the purposes of the controller design.

Transfer functions of the boiler are defined as the time-dependent functional relations between input and output variables. When one input variable (steam rate) is changed, the output variables under consideration (drum pressure and water level) change as a function of time in a manner determined by the boiler's dynamic equations. These relationships can be expressed in the following form:

$$\Delta P_B = E_{PS}\,\Delta w_S + E_{PF}\,\Delta w_F + E_{Pi}\,\Delta w_i \qquad (13A)$$
$$\Delta y = E_{YS}\,\Delta w_S + E_{yF}\,\Delta w_F + E_{yi}\,\Delta w_i \qquad (13B)$$

These expressions relate a change in the input variables steam rate Δw_S, fuel rate Δw_F, and feed-water rate Δw_i caused by a change in drum pressure ΔP_B and water level Δy from certain steady-state operating conditions. Interaction of the variables can be seen from these relations. The conventional boiler controller picks up pressure change ΔP_B and sends a signal to the blower-speed and damper-area control valves to adjust the fuel rate w_F, thus bringing the pressure to its normal value. The change in the fuel rate, however, causes a change in the water level Δy, according to Equation 13B; Δy has to be corrected by adjusting the feed-water rate. Thus, the drum pressure is again affected by the adjustment of Δw_i, so that fuel rate w_F has to be corrected again. Fortunately, the process is convergent and the controller is eventually able to bring everything back to normal.

The noninteracting controller will, in principle, adjust both fuel and feed-water rates in a prescribed manner when the steam flow rate changes so that neither drum pressure nor drum liquid level is disturbed. The controller will, then, receive signals from steam flow rate w_S, drum pressure P_B, and drum liquid level y, compare these with the set-points P_B and y, and adjust the feed-water and fuel rates. Hence, the functional relations for the controller are:

$$\Delta w_F = C_{F_P}(\Delta P_B)_e + C_{Fy}(\Delta y)_e + C_{FS}\,\Delta w_S \qquad (14A)$$
$$\Delta w_i = C_{iP}(\Delta P_B)_e + C_{iy}(\Delta y)_e + C_{iS}\,\Delta w_S \qquad (14B)$$

(The time-dependent coefficients E_{PS}, E_{PF}, E_{Pi}, E_{yS}, E_{yF}, and E_{yi} in Equations 13A and 13B are known from boiler dynamic analysis. But the controller transfer functions C_{FP}, C_{Fy}, C_{FS}, C_{iP}, C_{iy}, and C_{iS} still have to be determined.)

The following equations are obtained by substituting the values of Δw_F and Δw_i from Equations 14A and 14B into 13A and 13B:

$$\Delta P_B = (C_{FP}E_{PF} + C_{iP}E_{Pi})(\Delta P_B)_e + (C_{Fy}E_{PF} + C_{iy}E_P)\,(\Delta y)_e + (E_{PS} + C_{FS}E_{PF} + C_{iS}E_{Pi})\,\Delta w_S \qquad (15A)$$
$$\Delta y = (C_{Fy}E_{yF} + C_{iy}E_{yi})(\Delta y)_e + (C_{FP}E_{yF} + C_{iP}E_{yi})\,(\Delta P_B)_e + (E_{yS} + C_{FS}E_{yF} + C_{iS}E_{yi})\,\Delta w_S \qquad (15B)$$

Figure 8 shows Equations 15A and 15B in physicomathematical form. The boxes as drawn are the matrix relations between the inputs and outputs of both the controller and the boiler, while the lines indicate the flow of the signals generated by the two boxes. Set-points $\Delta\bar{y}$ and ΔP_B are necessary to change the steady-state drum pressure and water level. In general, however, only steady-state water level is changed for different steam loads.

Noninteraction may now be defined from Equation 15A and 15B. It is required: that drum pressure will not change ($P_B = 0$) for any change in the steam flow rate ($w_S \neq 0$) and water level ($y \neq 0$); and that for a change in pressure set-point ($P_B \neq 0$), drum pressure will respond in a manner prescribed by a transfer function H_P (s), which determines how (in terms of time) the drum pressure should change from one steady-state condition

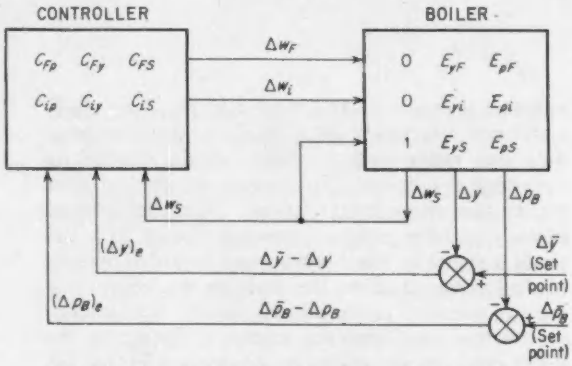


FIG. 8. Schematic showing the relations between the boiler and the noninteracting controller transfer functions.

to the new pressure set-point. As an example, $H_P(s)$ may state that drum pressure should change instantaneously when the new set-point is selected, but this is, of course, not reasonable on physical grounds and a more realistic choice of $H_P(s)$ is necessary.

The above requirements for noninteraction of pressure can be obtained from Equation 15A:

$$E_{PS} + C_{FS}E_{PF} + C_{iS}E_{Pi} = 0 \quad (16)$$
$$C_{Fy}E_{PF} + C_{iy}E_{Pi} = 0 \quad (17)$$
$$C_{FP}E_{PF} + C_{iP}E_{Pi} = H_P \quad (18)$$

A similar set of equations for noninteraction for water level y may be obtained, through the same type of reasoning, from Equation 15B:

$$E_{yS} + C_{FS}E_{yF} + C_{iS}E_{yi} = 0 \quad (19)$$
$$C_{FP}E_{yF} + C_{iP}E_{yi} = 0 \quad (20)$$
$$C_{Fy}E_{yF} + C_{iy}E_{yi} = H_y \quad (21)$$

Simultaneous solution of Equations 16 through 21 (containing six unknown controller transfer functions C_{FP}, C_{Fy}, C_{FS}, C_{iP}, C_{iy}, and C_{iS} determine the controller transfer functions.

From Equations 16 and 19:

$$C_{FS}E_{PF} + C_{iS}E_{Pi} = -E_{PS}$$
$$C_{FS}E_{yF} + C_{iS}E_{yi} = -E_{yS}$$

Hence: $$C_{FS} = \frac{E_{yS}E_{Pi} - E_{PS}E_{yi}}{D} \quad \text{and} \quad (22)$$

$$C_{iS} = \frac{E_{yF}E_{PS} - E_{PF}E_{yS}}{D} \quad (23)$$

where $D = E_{PF}E_{yi} - E_{Pi}E_{yF}$

From Equations 17 and 21:

$$C_{Fy} = -\frac{H_yE_{Pi}}{D} \quad \text{and} \quad C_{iy} = \frac{H_yE_{PF}}{D} \quad (24, 25)$$

From Equations 18 and 20:

$$C_{FP} = \frac{H_PE_{yi}}{D} \quad \text{and} \quad C_{iP} = -\frac{H_PE_{yF}}{D} \quad (26, 27)$$

A controller having the transfer functions defined by Equations 22 through 27 will be noninteracting; a change in steam-flow rate or water-level set-points will not affect drum pressure, and similarly, a change in steam-flow rate and pressure set-points will not affect water level.

Dynamic responses of the drum pressure and water level for three boiler inputs (Figures 5 and 6) are obtained from analog simulation of the boiler and are, of course, in the time domain. To get controller transfer functions C_{FP}, C_{Fy}, C_{FS}, C_{iP}, C_{iy}, and C_{iS}, boiler transfer functions have to be expressed in the frequency domain as E_{PF}, E_{Pi}, E_{PS}, E_{yF}, E_{yi}, and E_{yS}. For simplicity, transfer functions relating pressure to boiler input variables are approximated as single time constants in the form:

$$E_{PF} = \frac{K_1}{1+s\tau_1}; \quad E_{Pi} = \frac{K_2}{1+s\tau_1}; \quad E_{PS} = \frac{K_3}{1+s\tau_1} \quad (28A)$$

The transfer functions for water level are assumed as:

$$E_{yF} = \frac{K_4s+K_5}{(1+s\tau_1)(1+s\tau_2)}; \quad E_{yi} = \frac{K_6}{s}; \quad E_{yS} = \frac{K_7s+K_8}{s(1+s\tau_2)} \quad (29A)$$

(Actually, the characteristic determinant of the 18 equations derived by dynamic analysis is ninth order in s. Therefore, each transfer function theoretically contains nine time constants. Fortunately, only two or three time constants dominate and the rest can be neglected without appreciable loss of accuracy. This simplification eases the requirements for the

CONTROLLER NUMERICAL TABLE II—BOILER AND TRANSFER FUNCTIONS

The numerical values of gains and time constants in the boiler transfer functions are obtained from the open-loop transient responses, Figures 5 and 6. First a realistic time response for the variables is assumed; then the controller transfer function is obtained in numerical form, ready for synthesis and simulation. The development of these steps is shown below:

$$E_{PF} = k_1\frac{2.2}{40s+1}; \quad E_{Pi} = k_2\frac{-86}{40s+1}$$

$$E_{PS} = k_3\frac{-24.3}{40s+1} \quad (28B)$$

where k's are scale factors defining the correspondence between simulated and actual boiler variables. Similarly, Equations 29A take the form:

$$E_{yF} = k_4\frac{0.341s - 0.0028}{(3s+1)(40s+1)};$$

$$E_{yi} = k_5\frac{0.124}{s};$$

$$E_{yS} = k_6\frac{0.101s - 0.0063}{s(3s+1)} \quad (29B)$$

$H_p(s) = H_y(s)$ is assumed to be:

$$H_p(s) = H_y(s) = \frac{1}{5.88s(3s+1)} \quad (30)$$

Substituting these values into Equations 22 through 27, the controller transfer functions become:

$$C_{FS} = k_7\frac{14s^2+143s+3.56}{62.1s^2+11.5s+0.273} \quad (31)$$

$$C_{iS} = k_8\frac{-16.9s^2+0.401s+0.014}{62.1s^2+11.5s+0.273} \quad (32)$$

$$C_{Fy} = k_9\frac{585s+14.6}{62.1s^2+11.5s+0.273} \quad (33)$$

$$C_{iy} = k_{10}\frac{15s+0.374}{62.1s^2+11.5s+0.273} \quad (34)$$

$$C_{FP} = k_{11}\frac{33.7s^2+1.69s+0.021}{s(62.1s^2+11.5s+0.273)} \quad (35)$$

$$C_{iP} = k_{12}\frac{-(2.32s^2+0.039s-0.0005)}{(3s+1)(62.1s^2+11.5s+0.273)}$$
(36

controller and makes it more economical to construct.)

The analog computer results, Figures 5 and 6, give the open-loop responses of boiler pressure and water level to three step inputs. The gains K_1 through K_8 and time constants τ_1 and τ_2 can be determined from them. Then, simulated controller transfer functions are determined in numerical form from Equations 22 through 27, as shown in Table II for the Navy boiler under consideration.

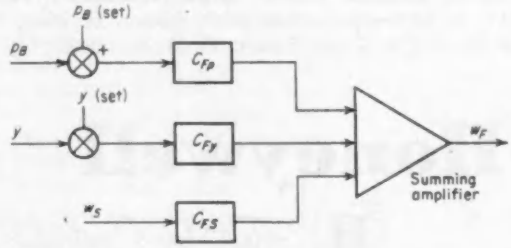
The controller transfer functions are shown in the controller box of Figure 8. Each transfer function is independent, from a hardware point of view. The internal connections between them and the inputs and outputs to the controller follow the matrix relationships specified by Equations 14A and 14B. Figure 9 shows in more detail the internal connections of the fuel-rate section of the noninteracting controller. Here, the computer carries out the multiplication and addition of signals as stipulated by Equations 14A. A similar arrangement for the feedwater rate controller would follow Equation 14B, and the two sections then would comprise the boiler's noninteracting controller. (The synthesis of the controller transfer function and the construction of the noninteracting controller for the boiler is the next stage of the project, and is now being carried out by Beckman for the Navy.)

Once the noninteracting controller is simulated on the analog computer, it can be used to control the simulated boiler. Figures 10 and 11 compare control by conventional proportional plus reset controllers. Figure 10 shows the variation of drum pressure for a step change in the steam flow rate. Theoretically, the drum pressure should not change at all when the boiler is controlled by the noninteracting controller, but due to the errors in potentiometer settings and the basic accuracy limitations of an analog computer, the drum pressure varies slightly. Nevertheless, the improvement in response over that obtained with the conventional controller is better by a factor of 10. It should be mentioned that the gain settings for the conventional controller were adjusted until an optimum response (minimum overshoot and settling time) was obtained in analog simulation.

Figure 11 shows the response of water level for a step change in steam flow rate; again the improvement obtained by the noninteracting controller over that of a conventional controller is several-fold. Shrink or swell is almost completely eliminated, and any variation in drum liquid level is due only to mismatch between the noninteracting control parameters.

The potentialities of the noninteracting controller are evident from this preliminary analysis. There may be some practical problems, it is true, that have to be overcome before a trouble-free noninteracting controller can be produced. But, the application of any new concept requires many, many hours of engineering before all the "bugs" are taken out of the system. The extra effort is well justified by the improvements that can be expected in boiler performance.

FIG. 9. Fuel-rate section of simulated noninteracting controller.



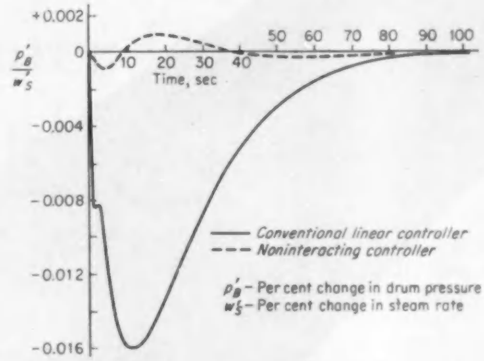


FIG. 10. Closed-loop response of drum pressure for a step-change in steam rate for the two controllers.

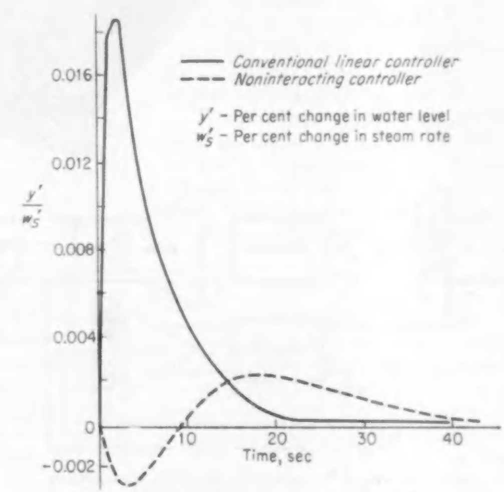
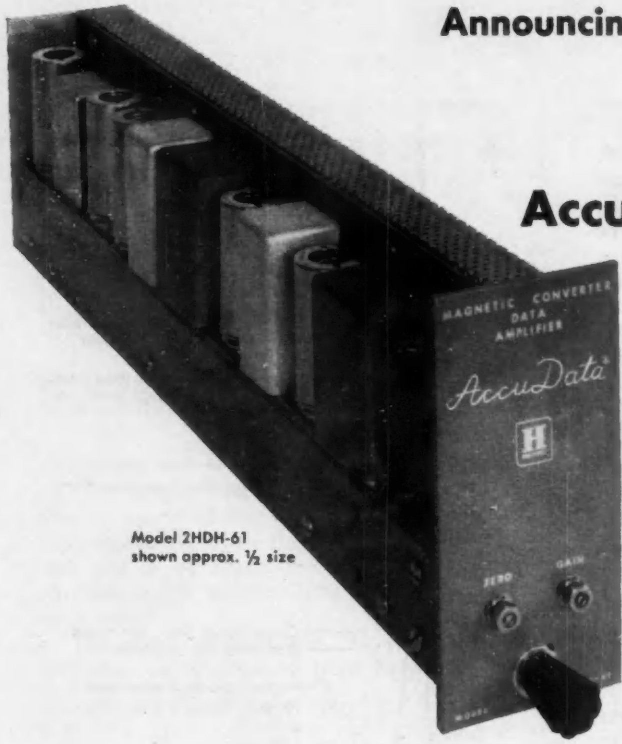


FIG. 11. Closed-loop response of water level for a step-change in steam rate for the two controllers.

Announcing

Honeywell AccuData I d-c Amplifiers

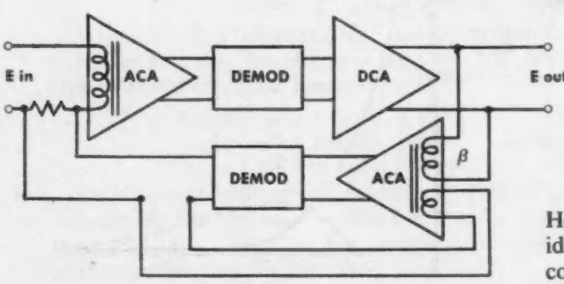


Model 2HDH-61 shown approx. ½ size

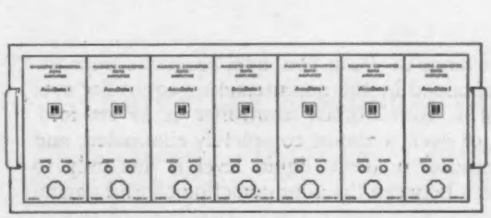
isolated differential input for strain gage, thermocouple and resistance bridge measurements

frequency response to 100 cps

100,000 ohm input resistance



The principal feature of this new development is a completely closed loop wideband feedback circuit which provides a highly accurate isolated signal connected in series opposition to the input emf.



The AccuData I d-c Amplifier is 5¼" high and is designed to mount seven to a 19" relay width. A frame assembly is available for this purpose. Separate power supplies (not shown) are used, having 2, 7, 14, or 49 channel capabilities.

Honeywell's new AccuData I d-c Amplifiers combine two Honeywell Second Harmonic Magnetic Converters to provide ideal d-c transducer preamplifier characteristics. Thermocouples, grounded or ungrounded; resistive strain gages operated from common power supplies; and other low-source impedance d-c devices are perfectly suited as inputs to this highly accurate d-c amplifier. The input circuit, with input impedance of greater than 100,000 ohms, is completely isolated from the output circuit and from ground.

The output is single-ended to match emf-input analog-to-digital converters. Overall non-linearity is 0.01%; gain instability, drift, and noise are less than 0.1%.

Other specifications: Response down 3 db at 100 cps; Rise time to 99.9% = 30 milliseconds; Input: 0 to 5 mv; Output: 0 to 1.0 volt; Output impedance: 0.01 ohms; Common Mode Rejection: at d-c virtually infinite; at 60 cps: 130 db (3,000,000 to 1).

Write for technical bulletin on the AccuData I, Model 2HDH-61, to Minneapolis-Honeywell, Boston Division, Department 34, 40 Life Street, Boston 35, Massachusetts.

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H HONEYWELL *First in Control*

New Computer for Multiple-Loop Transfer Functions

BERNARD LEE
McDonnell Aircraft Corp.

Here's a handy new instrument that reads directly in decibels and degrees to simplify the complex summations necessary to solve multiple-loop control systems by the inverse transfer function method.

The inverse transfer function describes a system in terms of a characteristic input to output ratio. A quick method for finding the inverse transfer function for certain common multiple-loop systems is described in a paper by Flannigan and Kirschbaum (Ref. 2). Briefly, it consists of accounting for all paths that an imaginary signal may take in traversing the system from output to input—in the direction of flow when negotiating a feedback element and against the flow when going through a forward element. The resultant inverse transfer function is the sum of the inverse functions from all possible paths through the system.

The overall inverse frequency response may be obtained by adding each term at each frequency. The addition involved, while not difficult, is laborious. Since the component parts are available in factored form, however, a Bode diagram may be constructed for each part (Ref. 3). With the magnitude and angle of each of the parts given by the Bode diagram, the sum may be obtained by laying off each part as a vector in the complex plane in head-to-tail fashion (Ref. 1).

Working principle

Consider the summation of the complex numbers $R_1e^{j\phi}$ and $R_2e^{j\psi}$ in Figure 1A. The magnitudes of the complex numbers are shown as lengths of directed lines, the angles as the angles described by these lines with respect to a common horizontal reference line. The sum of the two complex numbers is

$$Re^{j\theta} = R_1e^{j\phi} + R_2e^{j\psi} \qquad (1)$$

The magnitude of the sum R is the length of the line originating at the origin of $R_1e^{j\phi}$ and ending at the tip of $R_2e^{j\psi}$. If α is the angle between $Re^{j\theta}$ and $R_1e^{j\phi}$ then,

$$\theta = \phi + \alpha \qquad (2)$$

Consider the case where R_1 is greater than R_2. If R_1 is counter-rotated through ϕ deg and reduced to a unit length, as shown in Figure 1B, then the line having a length equal to the ratio R_2/R_1 can be directed so that it makes the angle of $\psi - \phi$ with the common horizontal reference. The length of the line joining 1 and $(R_2/R_1)e^{j(\psi-\phi)}$ is equal to the ratio R/R_1 and makes an angle α with the horizontal reference. Clearing the fraction R/R_1 by multiplying it by the magnitude R_1 yields the magnitude of the sum R. The angle θ is the sum of ϕ and α, as in Equation 2.

This is precisely the technique employed by the zero-db-circle computer, except that the magnitudes involved are considered in decibels. A directed line of unit length becomes zero decibels; a length corresponding to the ratio R_2/R_1 is readily laid off by subtracting the decibel value of R_1 from the decibel value of R_2. The actual resultant decibel value of R then is the sum of the decibel value of R_1 and the measured length of R. The overall frequency response is the combined inverse response, derived point by point from the Bode diagrams.

The zero-db-circle computer is pictured in Figure 2. It has two transparent linear scales pinned to a 10-in.-diam disc. The smaller scale, 5 in. long, rotates about the center of the disc and is calibrated from zero to minus 30 db. These calibrations represent the magnitude R_2/R_1. The angle, $\psi - \phi$, that the center line of R_2/R_1 makes with the horizontal reference is calibrated counterclockwise around the disc periphery from 0 deg to 360 deg.

The larger scale is 9.8 in. long and is calibrated in decibels from plus 6 db to minus 30 db. It represents the reduced sum of two complex numbers R/R_1 and rotates about the 180-deg point on the peripheral scale. The angle that its centerline makes with the horizontal reference corresponds to the angle α, and is calibrated counterclockwise around a partial circle from 0 to 60 deg and from 300 to 360 deg. The distance between the pivot points of the two scales corresponds to unit length or zero db.

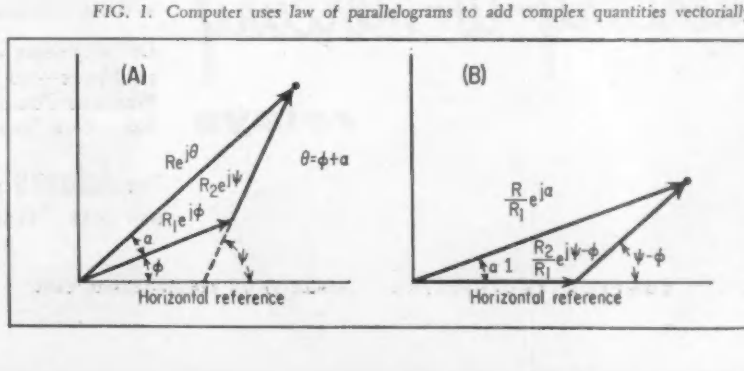
The two linear scales are connected together by a pair of sliding indices similar to those on a typical slide-rule. These indices slide together along their respective scales, and are pinned to rotate with respect to each other.

Using the computer

When combining frequency responses point by point, the centerline of the smaller linear scale is oriented at an angle corresponding to the difference between the phase angles associated with the smaller and larger magnitudes. With this orientation fixed, the indices are translated along the scales until the hairline associated with the smaller scale is in coincidence with a decibel value equal to the difference between the magnitudes of the smaller and larger quantities.

The reduced sum is then read directly under the index associated with the larger scale. The angle α is read from the partial circle, as indicated by center line of the larger scale. If the larger magnitude is now added to the reduced sum and its associated phase angle added to the angle α, the result corresponds to the sum of the two

FIG. 1. Computer uses law of parallelograms to add complex quantities vectorially.



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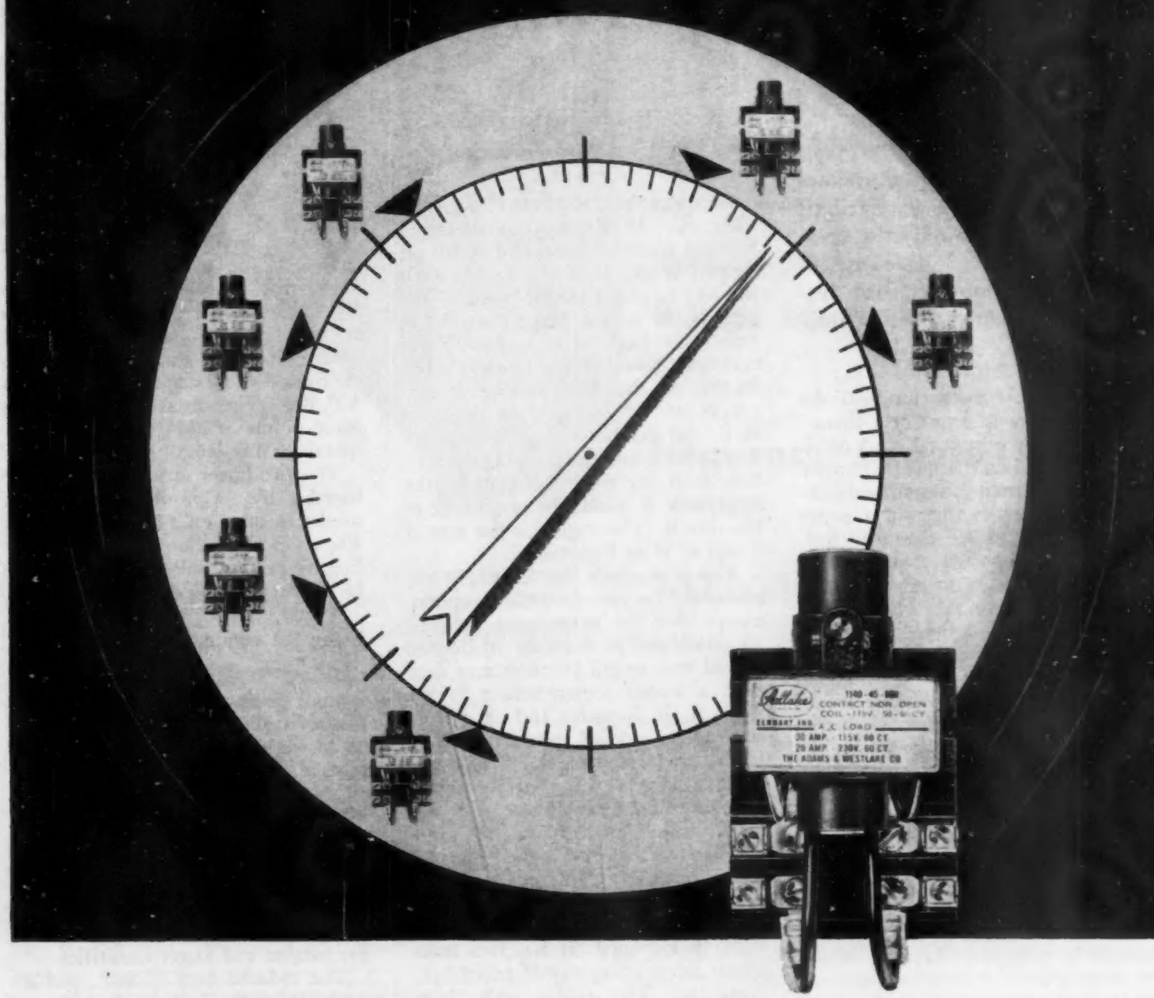

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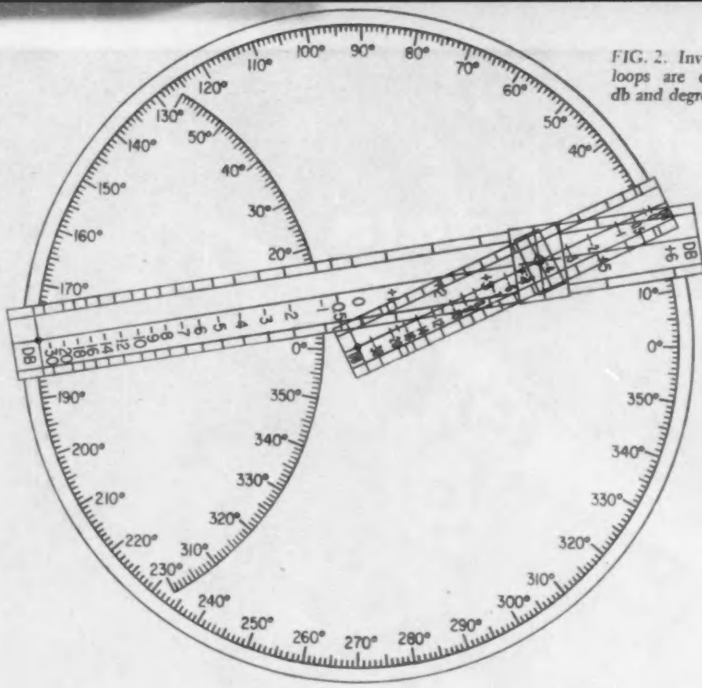

FIG. 2. Inverse transfer functions of individual loops are entered on computer directly in db and degrees; complex sum is read same way.

complex numbers. When the sum is the value of the overall inverse frequency response at the frequency under consideration, the negative of both the magnitude and phase angle corresponds to the overall forward frequency response.

The author acknowledges the contribution of Mr. G. H. Servos of Bendix Aviation Corp. to the physical design of the zero-db-circle computer.

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1. *PARALLEL CIRCUITS IN SERVOMECHANISMS*, H. T. Marcy, "AIEE Transactions", 65, 1956, p. 521.
2. *THE WRITING OF CLOSED-LOOP CONTROL TRANSFER FUNCTIONS BY INSPECTION*, J. B. Flannigan and H. S. Kirschbaum, "AIEE Transactions," 71, 1952, p. 91.
3. *NETWORK ANALYSIS AND FEEDBACK AMPLIFIER DESIGN*, H. W. Bode, Van Nostrand, 1945, pp. 303-359.

Heater Zeros Differential Transformer

H. W. ASHTON and W. F. BARTOE, Rohm & Haas Co.

Improvements in linear differential transformers and their associated amplifiers and servomechanisms have made it possible to detect and indicate or record displacements as small as 10 microin. But such sensitivities are not used conveniently because the reference point or zero of the LDT depends on the relative positions of associated equipment and generally varies with ambient temperature. This problem has been met squarely in a thickness measuring unit installed recently on a plastics production line.

In this application, the length of the armature shaft on the LDT is controlled by thermal expansion. The shaft is heated by a small coil wound on an aluminum V-block form and attached as shown in Figure 2. Normal operation (transformer zeroed) with the shaft somewhat above ambient temperature permits negative adjustments of displacement by reducing coil current and hence shaft temperature, and positive adjustments by increasing current.

Direct current is used in the coil to avoid the possibility of ac pickup by the transformer winding. It has been found that 6 volts across a heater coil of 100 ohms increases the length of a stainless steel transformer shaft about 0.0005 in. per in. over its length at ambient (room) temperature. Heater current is supplied from a square-law potentiometer that can be adjusted manually or automatically.

In the thickness measuring unit, a readout circuit is programmed to check LDT zero at times when no quantity is being measured (Figure 1). Signals to the 9, 8, 7, and 6 solenoids in the units column of the data printer connect to an electronic relay which controls the potentiometer drive motor, and close the relay for one unit of positive adjustment. Signals to the 1, 2, 3, and 4 solenoids close the relay in the opposite direction to produce a unit of negative adjustment. Heating time lag is balanced against relay hold-in time to eliminate overshooting of adjustment.

FIG. 1. Heater is supplied dc from motor positioned potentiometer. Motor is driven in timed steps by electronic relay.

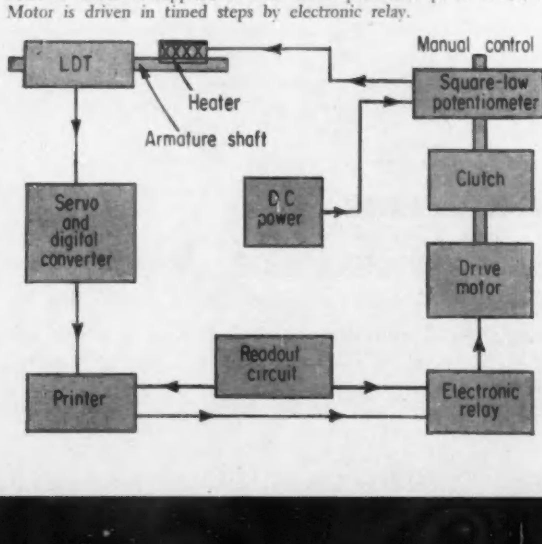
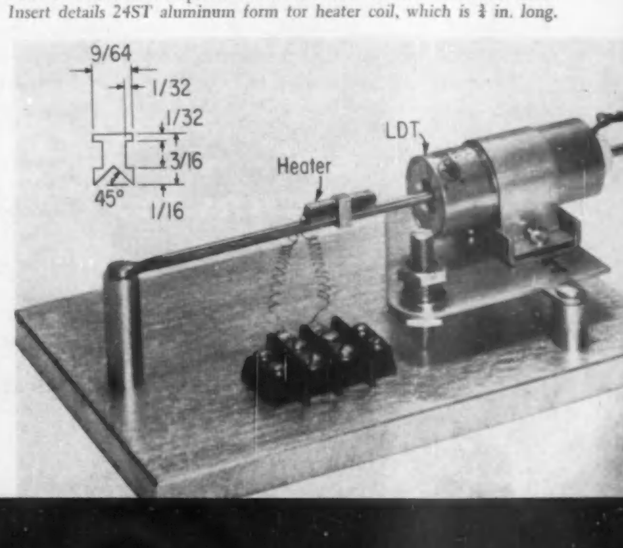


FIG. 2. Photo shows special heater mounted on LDT armature shaft. Insert details 24ST aluminum form for heater coil, which is ¾ in. long.



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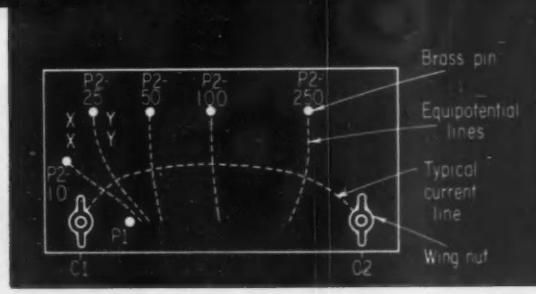
Multirange Microhm Reference Resistors

F. J. LINGEL, General Electric Co.



Multirange resistance reference is a 2½ x 5 x 1/16 in. strip of manganin, mounted on bakelite. Effective resistances to known current flowing between C1 and C2 are indicated by millivolt drops between P1 and various P2 points marked in microhms.

A multirange microhm resistance reference has been designed and constructed with two unique features: the low microhm taps on the reference are spaced for easy practical connection of instrument leads; and the apparent resistance values between the various taps and the common connection can be adjusted up or down by removing metal from the reference strip. A multirange ammeter shunt has also been designed around the same principles.

The design is based on a study of current flow distribution in a flat strip when the current source is connected near two adjacent corners. Figure 1 is a drawing of the microhm reference, which is a single flat 1/16-in. thick strip of manganin, 2½ by 5 in. The current connections are ¼-20 brass screws silver-soldered to the strip ½ in. from the lower corners.

In preliminary experiments, it was found that greater spacing could be provided between the low microhm positions by setting the points along the upper edge of the strip. A check of the equipotential points gave the pattern shown in the figure, measuring from *P*1. The current lines run at right angles to the equal potential lines. Note how some of the current flows from C_1 up along the top of the strip and back to C_2. Recognizing this made it possible to more easily set the low microhm points and to establish clearance between the points for the connecting clips.

For example, if the 10- and 25-microhm points were in a straight line between C_1 and C_2, there would only be 1/16 in. between them. By locating them along the top, however, they were more than ⅜ in. apart. This also makes it possible to use relatively thin material to obtain very low reference resistors; i.e., it is no longer necessary to use a thick low resistance strip of material to obtain a low value resistor.

The exact millivolt drop between the potential points and *P*1 is adjusted by grinding material from the reverse side of the strip. This operation uncovers the second unique feature. By grinding to the left of *P*2-25 in the area marked XX, Figure 1, it is possible to raise the millivolt drop and hence the resistance between *P*1 and *P*2. This has the usual explanation—it is due to the decrease in cross-section. By grinding to the right of *P*2-25 in the area YY, however, the millivolt drop between *P*1 and *P*2 is found to decrease. This is explained by referring to change in current flow; that is, part of the current between C1 and C2 is diverted to other parts of the strip, and the local decrease in current then decreases the voltage drop and the effective resistance between *P*1 and *P*2.

A multirange ammeter shunt was made, using the same principles, for a 0-5 millivolt instrument from a standard 100-amp, 50-mv shunt strip.

Note that the resistance to a current flowing between a millivolt pin and *P*1 will not be the same as the resistance indicated by the millivolt drop between these points for a current flowing from C1 to C2, because the current distribution pattern will be very different. This resistance reference must be used as a millivoltage source with a known current flowing between C1 and C2.

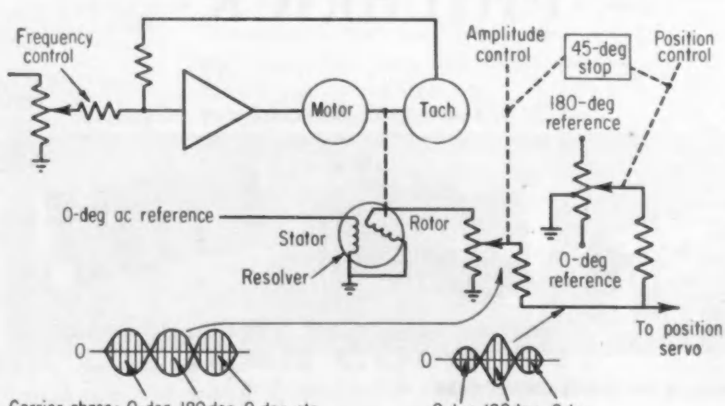
Sinusoidal Signal Generator for Ac Servos

A three-axis flight simulator manufactured by J. W. Fecker, Inc., uses the simply conceived electromechanical signal generator shown in the accompanying diagram to produce variable low-frequency sinusoidal inputs for the ac position servos that drive its three axes. A resolver, when its stator is excited by a constant-amplitude ac reference voltage, produces an output that varies sinusoidally in amplitude at the frequency at which its rotor is turned. This signal is exactly of the form required by a conventional ac servoamplifier, switching from 0-deg reference phase to 180-deg reference phase in every half-cycle.

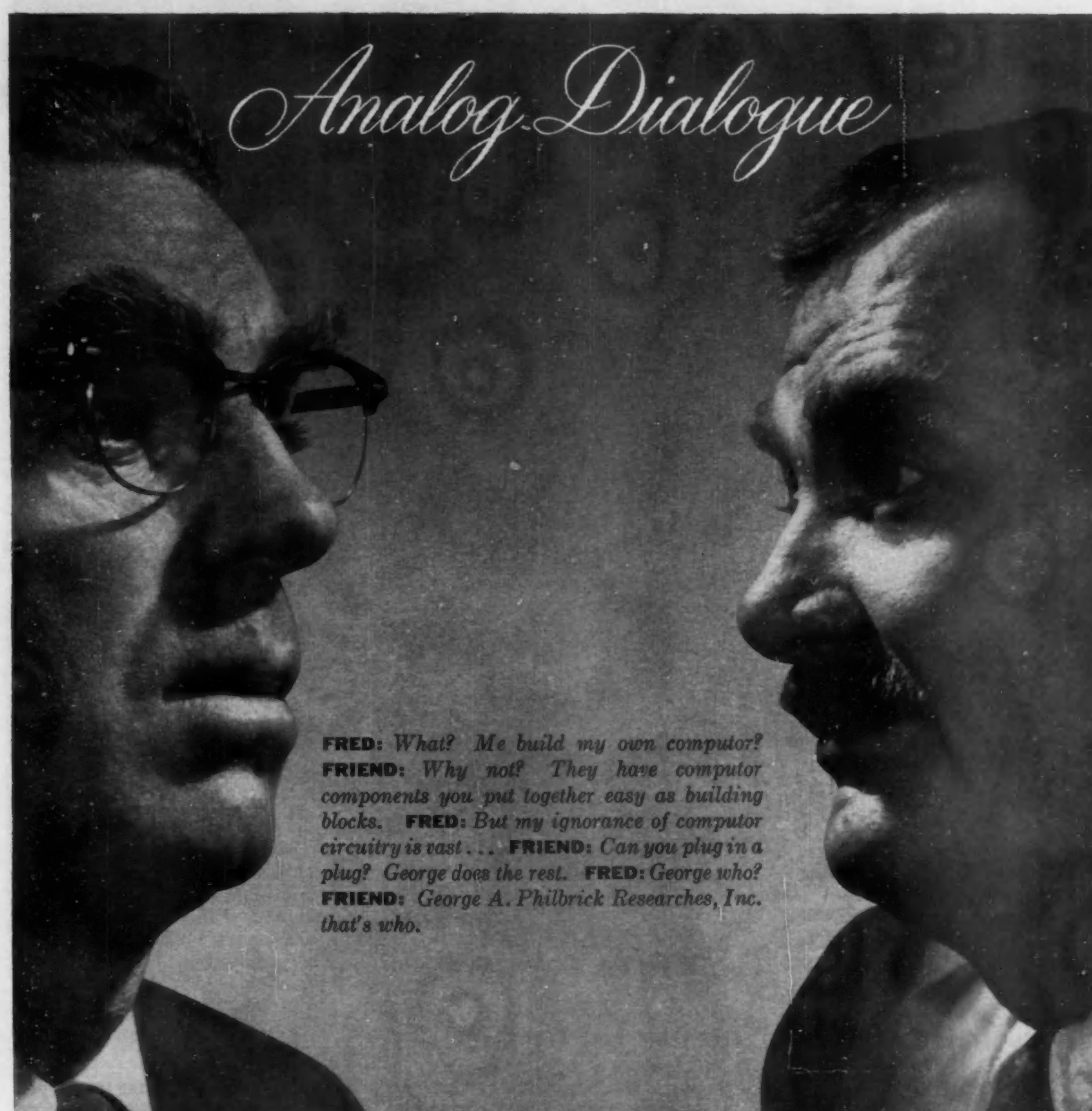
In the flight simulator, the resolver is turned by an ac velocity servo. Thus, the frequency control for an axis motion is simply a potentiometer across an ac voltage source.

The sinusoidal output of the signal generator is supplied to the axis position servos, which drive the simulator axes through ranges of angular position that depend on the percentage of the signal generator output used. The desired percentage is selected by the amplitude-control potentiometer and limited to 45 deg.

A static position signal is added so that each axis can oscillate about any selected angular position in its range.



Resolver driven by velocity servo is an easily controlled source of low-frequency sinusoidal signals for driving ac position servos. This generator's frequency, amplitude, and position are controllable by ordinary potentiometers.



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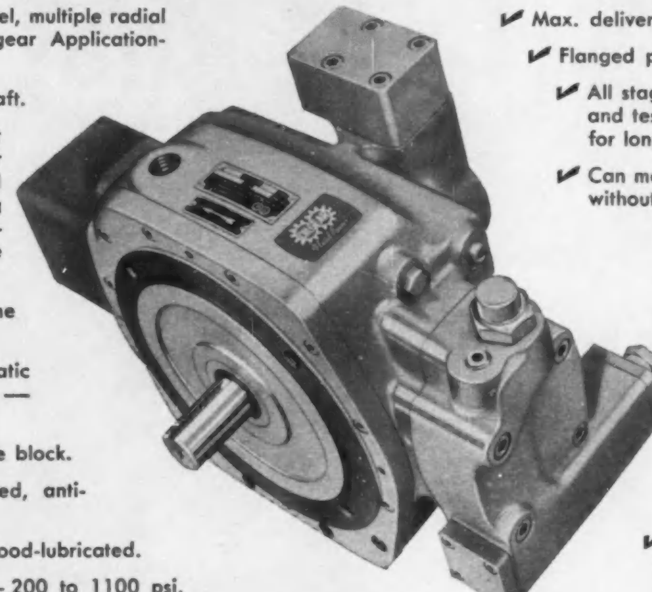

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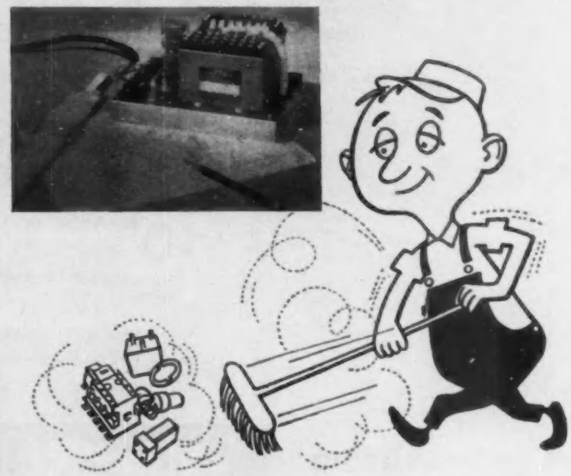

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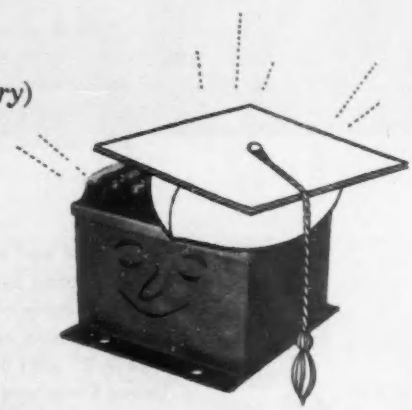
LOGIC, MY DEAR WATSON *(. . . is elementary)*



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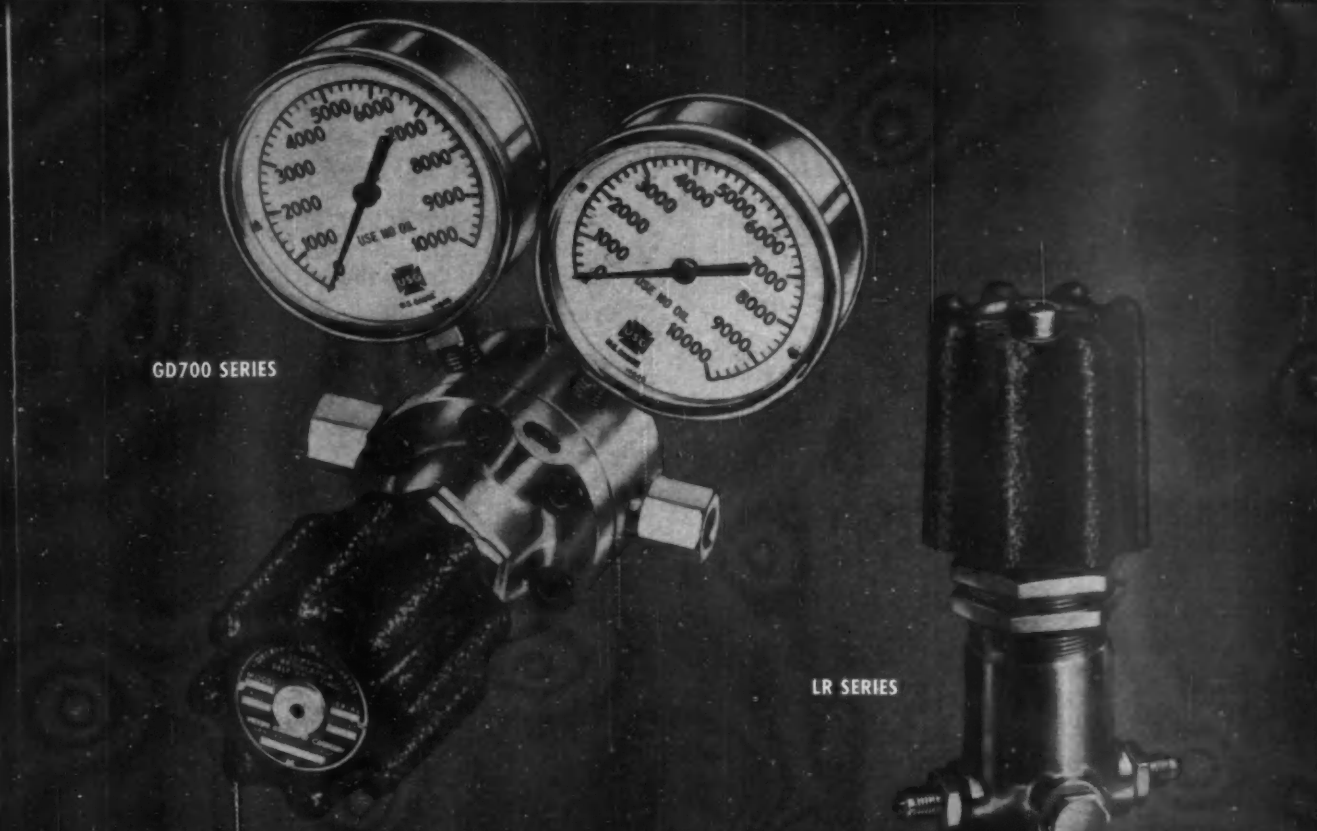

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GD712	7000	200-2000	10,000- 4,000
GD713	7000	50- 800	10,000- 1,000
GD714	7000	10- 150	10,000- 200
GD700	3600	200-3600	5,000- 5,000
GD701	3600	200-2000	5,000- 4,000
GD702	3600	50- 800	5,000- 1,000
GD703	3600	10- 150	5,000- 200

Flow: Approx. 300 scfm. Leakage: None.
Operating temp. range: −67° F to +200° F (Storage −80° F)

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LR19B	7000	20-3600
LR18B	7000	15-2000
LR17B	7000	10- 800
LR16B	7000	5- 200

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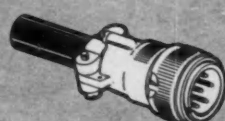

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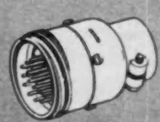

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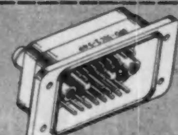

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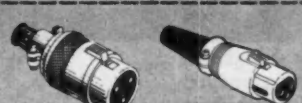

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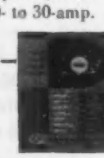

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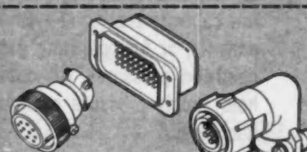
for RADIO and SUB-MINIATURE applications



D, MC, DPA, DPX, AND K MINIATURES... miniatures and sub-miniatures designed for amplifiers, miniature indicators, computer circuits, telemetering equipment, small pre-amps, and general instrumentation where space is limited and current requirements are generally not over 5 amperes. Variety of shell styles, junction shell, and insert arrangements. 3 to 50 contacts, plus coaxials.

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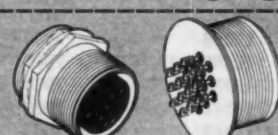
for HERMETICALLY SEALED applications



GS (MS TYPE), KH, RKH, DAH, BFH, TBFH, DBH, KH30... with steel shells and contacts to withstand high pressures from within or without. Insulation is a glass material, fused under high temperature to shell and contacts, thus forming a hermetic seal.

---

for HIGH TEMPERATURE and firewall applications

MS-K, MS-"FW," AND CANNON K-"FW" STEEL SHELL CONNECTORS... Open flame protection offered in the greatest variety of this type of connector. Wall- or box-mounting receptacles. Straight or angle 90° plugs. Crimp-type contacts. Inserts of glass-filled materials.

Send for AR Condensed Catalog containing illustrations and technical information on all principal series of connectors in the extensive Cannon Line.

CANNON ELECTRIC COMPANY, 3208 Humboldt St., Los Angeles 31, California. Factories in Los Angeles, Salem, Mass., Toronto, Can., London, Eng., Melbourne, Austl. Manufacturing licensees Paris, Tokyo. Representatives and distributors in all principal cities.

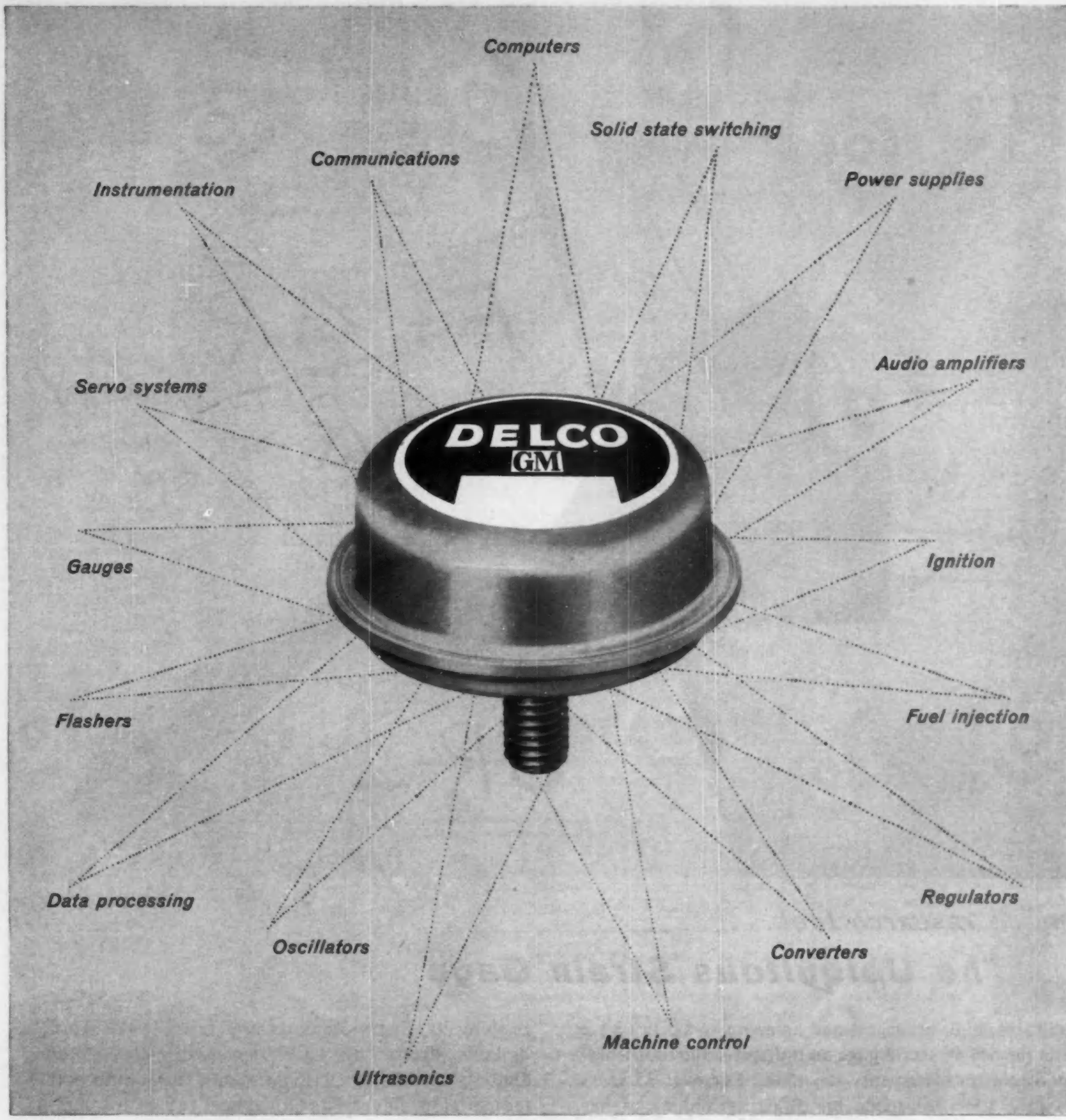
please refer to Dept. 422

CANNON ELECTRIC

Since 1915

 CIRCLE 66 ON READER-SERVICE CARD

CIRCLE 67 ON READER-SERVICE CARD



Wherever you require high power, consider

DELCO HIGH POWER TRANSISTORS

Thousands of Delco high power germanium transistors are produced daily as engineers find new applications for them. In switching, regulation, or power supplies—in almost any circuit that requires high power—Delco transistors are adding new meaning to compactness, long life and reliability.

All Delco transistors are 13-ampere types and, as a family, they offer a collector voltage range from 40 to 100 volts. Each is characterized by uniformly low saturation resistance and high gain at high current levels. Normalizing insures their fine performance and uniformity regardless of age. Also important—all Delco transistors are in volume production and readily available at moderate cost.

For complete data contact us at Kokomo, Indiana or at one of our conveniently located offices in Newark, New Jersey or Santa Monica, California. Engineering and application assistance is yours for the asking.

BRANCH OFFICES

Newark, New Jersey
1180 Raymond Boulevard
Tel: Mitchell 2-6165

Santa Monica, California
726 Santa Monica Boulevard
Tel: Exbrook 3-1465

DELCO RADIO

Division of General Motors
Kokomo, Indiana

 CIRCLE 68 ON READER-SERVICE CARD

NEW PRODUCTS

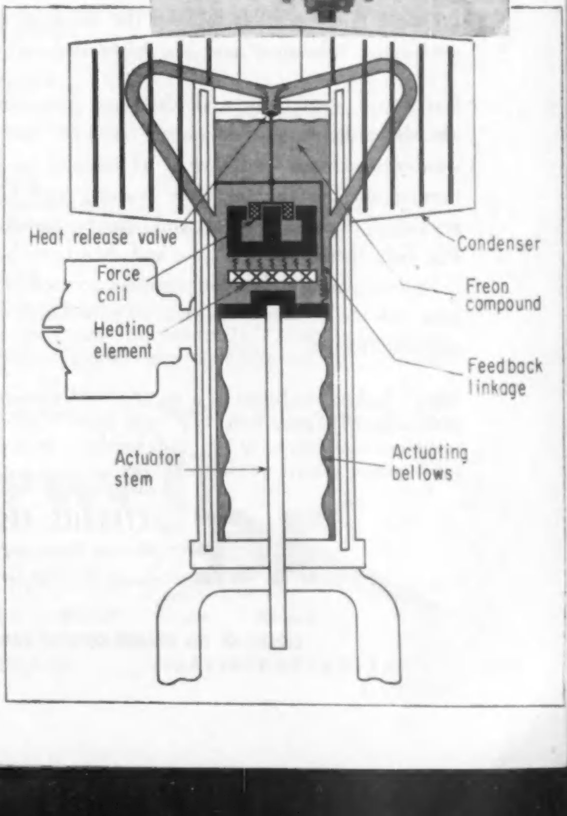
NEW ACTUATOR gets thrust from gas.

Swartwout's new Thermo-Drive valve actuator, designed for simplicity, uses controlled gas pressure as its motivating force. This pressure, obtained by heat-vaporizing a self-contained fluid, eliminates the need for any external power supply such as air in the case of pneumatic actuators, or a motor-pump combination in the case of electrohydraulic units. Noncritical with respect to power input, ambient temperature and other environmental factors, the Thermo Drive actuator proved on test to have an operating life of over 1 million full strokes. Manufacturer claims that under normal field conditions, the unit requires no maintenance or adjustment.

The accompanying photo shows the unit mounted on a standard double-seated valve; the drawing illustrates its operating principles. An electric heating element causes continuous vaporization of a Freon compound (shaded area) in which all parts are submerged. Vaporization creates pressure within the actuator body. A force coil coupled to a stem-position feedback arrangement and a heat-release valve receives the electrical signal, regulating the release of vapor to a cooling condenser, where the vapor liquifies and circulates back to the actuator body. When the controller calls for a reduced heat-release rate, pressure builds up in the actuator and compresses the spring-bellows. This drives the valve stem downward. When heat release increases, the bellows expands, causing an upstroke. Thus, the force coil adjusts gas pressure and positions the actuator stem until balance is effected between heat input and heat release. Should heat release change because of an ambient-temperature change at the cooling condenser or should heat input vary because of change in heating-coil voltage, the heat-release valve moves correspondingly but maintains the gas pressure (stem position) at the value called for by the controller signal.

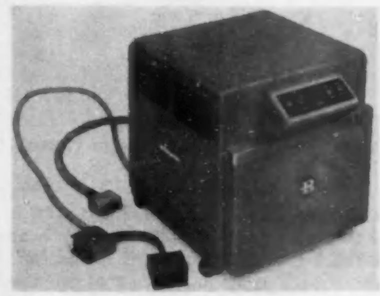
Specifications—Electrical design suitable for Div. 1 locations, with nonflammable, nonexplosive, nontoxic Freon fluid contained under hermetic seal construction. Input signal—1.0 to 5.0 ma dc into 12,000 ohms; sensitivity—0.1 percent of input range; load sensitivity—less than 1.5 percent displacement produces full rated thrust; speed of response—0.1 in. per sec; repeatability—0.5 percent; stroke—1.5 in.; max stem loading—actuating force 500 lb opposed by 300-lb spring return force; ambient air temperature range—minus 50 to plus 140 deg F; stem retracts on power failure; 115 volts ac or dc unregulated power supply required; valve-position indicator is standard, hand-wheel operator optional.—The Swartwout Co., Cleveland, Ohio.

Circle No. 200 on reply card



NEW PRODUCTS

DATA HANDLING & DISPLAY



PUNCHED-CARD INPUT

Designed to increase the flexibility of the E101 computer, this new punched-card input unit permits the use of separate or intermixed data and instructions. An automatic-to-manual switch lets the operator choose between reading data directly from punched cards or from a modified version of a standard card keypunch. Instructions entered manually from the keypunch can be simultaneously punched into cards. Speed ranges from 17 to 20 card columns per sec, depending on the keypunch model used.—Burroughs Corp., Pasadena, Calif.

Circle No. 201 on reply card

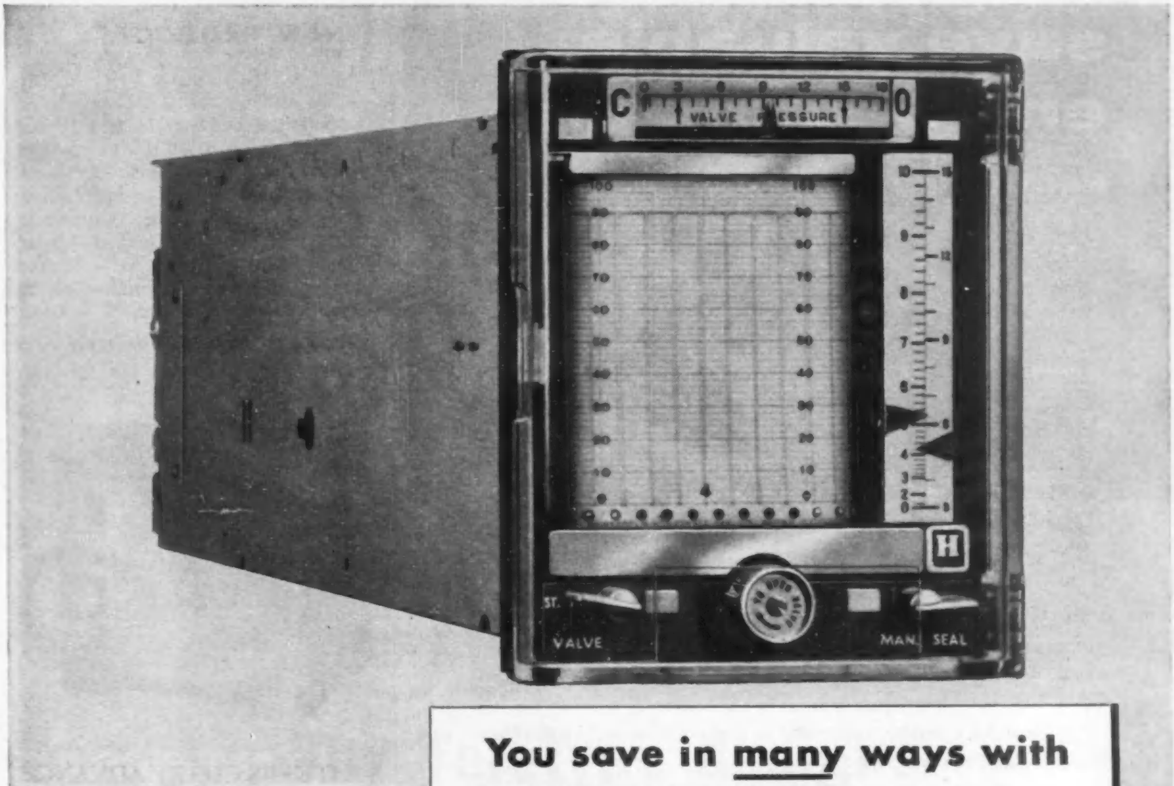
HANDLES 96 STRAIN GAGES

Strain-gage recording systems are now available for balancing, calibrating, controlling, and recording the output of from 24 to 96 separate strain-gage channels. These modular units provide for direct recording of strain values on multipoint strip chart recorders. Models are available for producing either printed or plotted records. Systems also include a programmer and regulated power supply. —B & F Instruments, Inc., Philadelphia, Pa.

Circle No. 202 on reply card

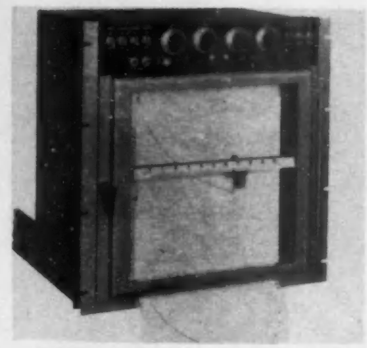
BUFFER MEMORY

The Model 144M4A is a 144-character, four-bit, sequential-in, sequential-out buffer memory system designed for use as a time buffer between equipments of different operational speeds. It operates in ambient


VALVE
MAN SEAL

temperatures between 15 and 50 deg C, at speeds up to 100,000 cycles per sec for load or unload operations. Self-contained, the unit includes power supply, address counters, output registers, drive circuits, and a timing generator, as well as the required number of memory planes.—General Ceramics Corp., Keasbey, N. J.

Circle No. 203 on reply card

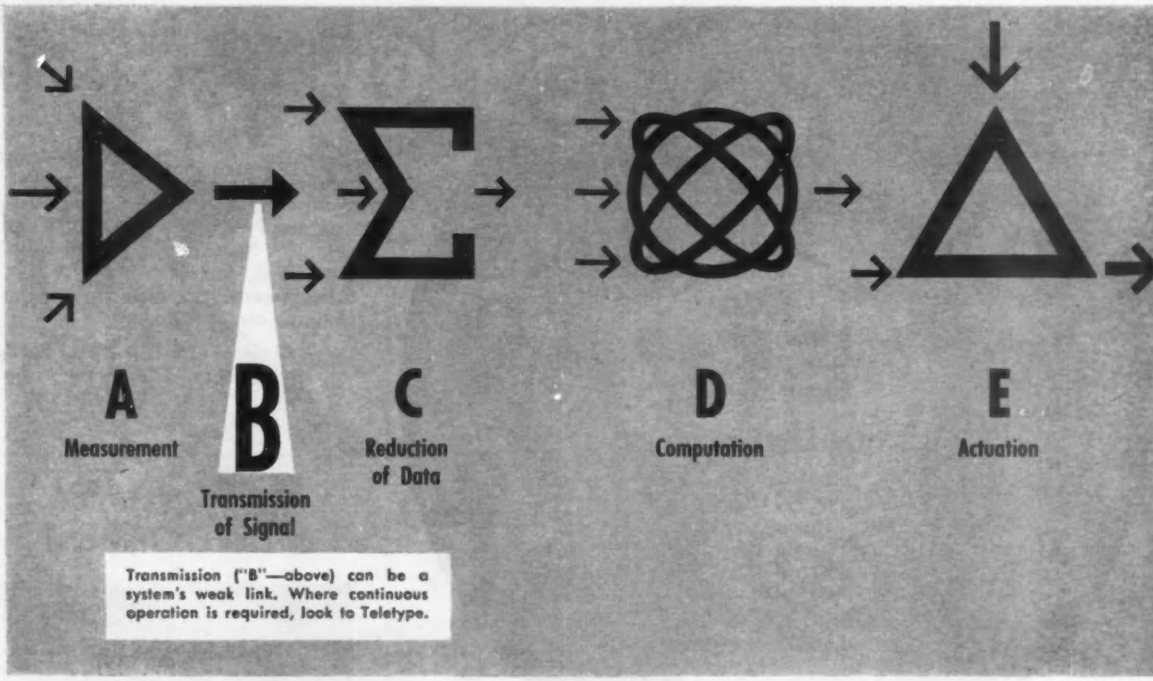


FEATURES CHART ADVANCE

Shown is the Model 6 Autograf X-Y recorder, a rack-mounted, completely self-contained unit for drawing and following curves and plotting points from two variables wherever data can be reduced to electrical form. A single roll of 100 complete charts may be advanced into position either manually or automatically; a built-in vacuum system holds the paper firmly in place during the actual recording process. Charts measure 10 in. by 10 in. Input voltages on each axis range from 5 millivolts dc to 500 vdc. Accuracy is better than 0.25 percent, full-scale.—F. L. Moseley Co., Pasadena, Calif.

Circle No. 204 on reply card

PLUS. . . .
(205) A card-programmed **function generator**, offered by **Mid-Century Instrumatic Corp.**, New York, combines conventional diode-breakpoint circuitry with punched paper card input. . . . (206) **Marion Electrical Instrument Co.**, Manchester, N. H., recently introduced a new **edgewise meter** that provides an easily read display on a 1 7/16-in. scale. . . . (207) Developed by **Durant Mfg. Co.**, Milwaukee, Wis., the Model 5-YE-9156-ER hermetically-sealed **electric counter** meets MIL spec 5272-A and has a maximum electrical reset time of



Why Teletype designs for continuous operation

It was a must! Teletype cut its teeth working in railroad stations too far away for servicing, in newspaper and commercial telegraph jobs that ran around the clock, on the floor of the stock exchange where a breakdown could cost a fortune . . . and in rough hitches with the Armed Forces.

The discipline demanded by these jobs is a part of each machine.

Attention Free. The Teletype Model 28 printer is designed for minimum maintenance. Lubrication interval at 100 word per minute speed is 1,500 hours—at 60 word per minute it's 3,000 hours! Motors were specially designed for the Model 28, to give long, attention-free operation. The printer is not affected by tilting or severe vibration, works reliably even in mobile applications. Other attention-free features:

1 New type box. Characters are contained in a compact, lightweight assembly. Each character is on a separate pallet—type alignment is built in, overscoring and underscoring eliminated. The type box can be quickly removed, without tools, for cleaning or changes in type arrangement.

2 Tests at 100 WPM in continuous operation show 9,000,000 words printed, without servicing. Paper guides and pressure rollers are designed to provide straight-line paper feed, insuring accurate, continuous, paper alignment.

3 All steel clutches give firm, uniform, and accurate engagement, cycle after cycle . . . operate with exceptional stability . . . deliver high torque capable of handling positive and negative loads. Internal expansion principle in clutch design minimizes wear. Lubrication interval is reduced to once or twice a year.

New—Versatile, too. The Teletype Model 28 printer is a new instrument . . . engineered to "cruise" at 100 WPM. It is attractively styled and quiet in operation.

Exclusive with the Teletype 28 Printer is the versatile Stunt Box, which is actually a "robot brain." Responding to keyboard or line signals, it may be used for internal control of extra functions in the Teletype printer and for remote control of associated or other electronic or mechanical equipment.

For more information about this Teletype Model 28 printer—write to Teletype Corporation, Dept. 20K, 4100 Fullerton Ave., Chicago 39, Illinois.

TELETYPE®
CORPORATION
SUBSIDIARY OF *Western Electric Company* INC.

105 msec. . . . (208) A new compact **annunciator** with flashing sequence alarm and no drain circuit has been designed by **Panellit, Inc.**, Skokie, Ill. . . . (209) **Standard Instrument Corp.**, New York, announced a new **electronic counter** for high-speed manufacturing processes.

Circle No. 205, 206, 207, 208 or 209 on reply card

RESEARCH, TEST & DEVELOPMENT

FOR CABLE TESTING

SPACE (for a Self-Programming Automatic Cable Evaluator) is a console-mounted test instrument that automatically checks for high-potential leakage and continuity between any and all terminations of a cable harness. Using a computer-type memory, it progresses through a series of tests in a logical manner at a maximum rate of 10 tests per sec, and can generate its own tape program. The instrument shown can handle 420 terminations, but other capacities are available. Unit includes two scanning circuits, a tape reader and code storage unit, a motorized tape punch, output printer, and leakage and continuity detection circuitry. – James Cunningham, Son & Co., Inc., Rochester, N. Y.

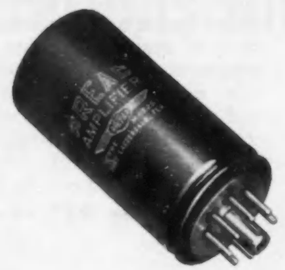
Circle No. 210 on reply card

BAR-GRAPH, SCOPE

An ac bar-graph oscilloscope simultaneously displays up to 40 separate signals on a cathode-ray tube. Desig-

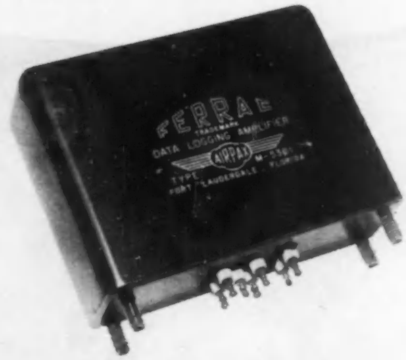
ALL NEW!

AIRPAX items now in production



PREAC

Single stage magnetic computor amplifier produces 3 volt output with sub-microwatt input signal

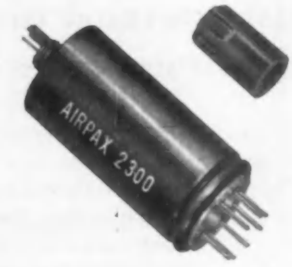


DATA LOGGING AMPLIFIER

Three stage magnetic amplifier, unusually low null drift. Used with thermocouples, strain gages, and like transducers.

TACH-PAK

All electronic speed measurement device permits tachometry with an accuracy of 0.1%—simple, inexpensive

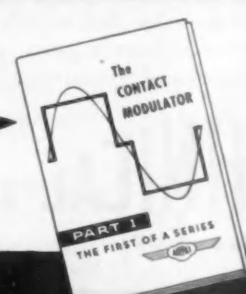


LOW NOISE CHOPPERS

. . . with sub-microvolt noise levels for instrument amplifiers, null seeking servos and similar uses

THE CONTACT MODULATOR

PART I of the new series of booklets on the CONTACT MODULATOR is just off the press. Send for your free copy.



AIRPAX

L4

THE AIRPAX PRODUCTS COMPANY

CAMBRIDGE, MARYLAND FORT LAUDERDALE, FLORIDA BALTIMORE, MARYLAND

nated Model AC-40BG, the unit permits continuous visual monitoring of multichannel data from thermocouples, strain gages, piezoelectric pressure gages, flowmeters, spectrometers, and other primary elements. Applications include the monitoring of jet-engine temperatures, measurement of strain distribution in aircraft structures, determination of temperature distribution in refinery units, and many other military or industrial test procedures.—Industrial Products Div. of International Telephone & Telegraph Corp., Lodi, N. J.

Circle No. 211 on reply card

OFFERS HIGH ACCURACY

By means of a thermistor sensing element and a Brown strip chart recorder, this instrument provides an accuracy of within 1/1,000 deg C on a full scale of ½ deg C. Called the Model 102 Temperature Recorder, it covers a temperature range of 20 to 30 deg C. A selector switch permits operation within any ½-deg portion of this range. An internal battery provides for calibration and balancing.—Fenwal Electronics, Inc., Framingham, Mass.

Circle No. 212 on reply card

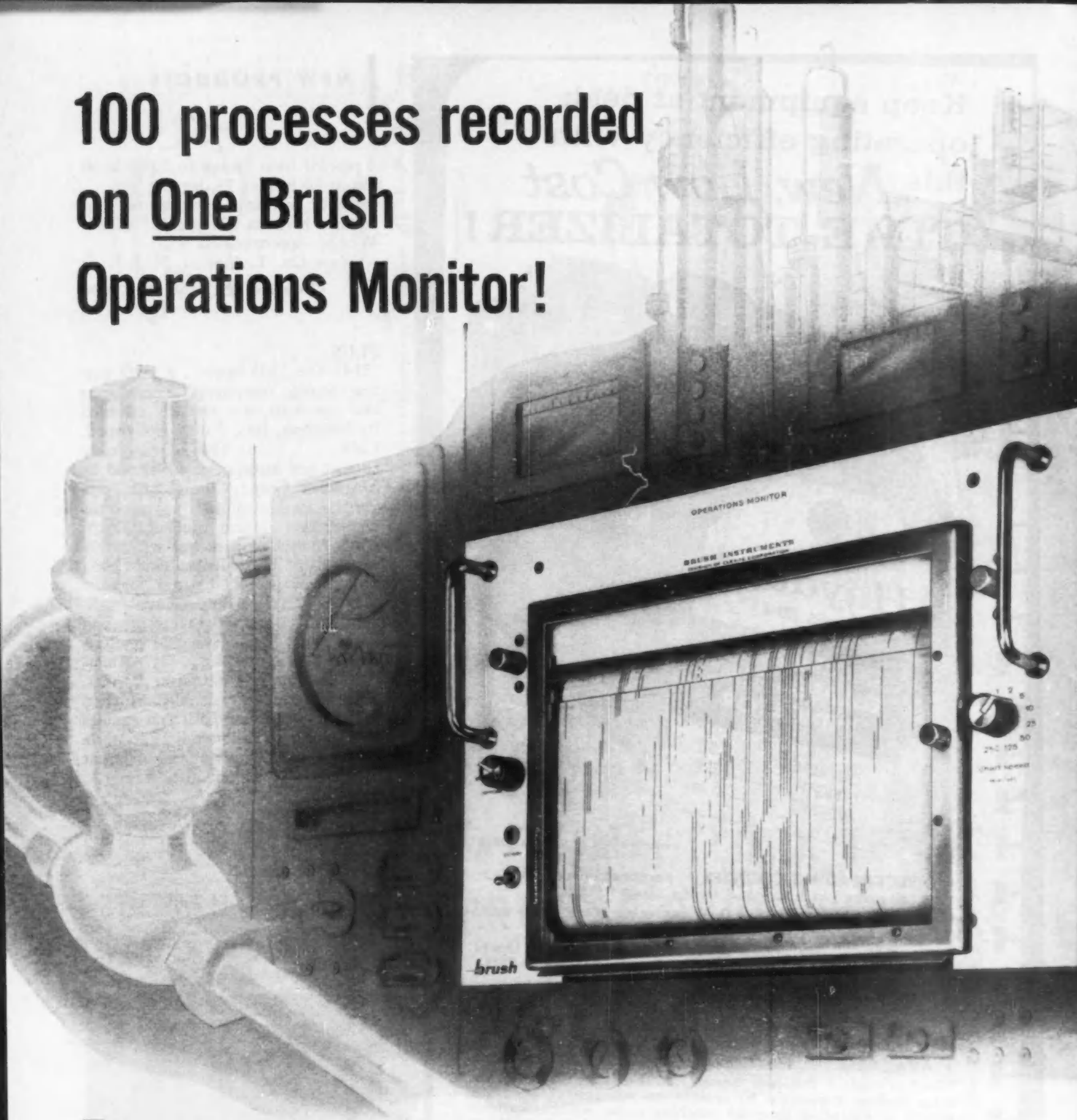
STABLE VOLTMETER

Designed to measure ac voltages over a frequency range of 10 cycles to 1,000 kc, the Model 21A electronic voltmeter will also serve as a null indicator, as a power level meter, and as a wide-band amplifier.

Characteristics:

Accuracy: within 2 percent from 15 cps to 200 kc at 25 deg C and within

100 processes recorded on <u>One</u> Brush Operations Monitor!



This compact Brush Operations Monitor can improve the control of power distribution systems, chemical processes and automated production lines.

On a moving chart only 12″ wide, 100 separate operations can be recorded at the same time . . . what happens or doesn't happen . . . monitoring present recording and indicating devices. For example, the opening or closing of a valve . . . the action of a relay . . . the control of motors . . . all are documented in a time relationship to other operations. You get an immediate picture of an *entire situation* at any time. Sixteen different time bases can be selected from remote or on-the-spot locations.

Write to Brush for details. Engineering assistance is available at all Brush factory branches, strategically located throughout the United States.

brush INSTRUMENTS
DIVISION OF
3405 PERKINS AVENUE **CLEVITE** CORPORATION CLEVELAND 14, OHIO

CIRCLE 76 ON READER-SERVICE CARD

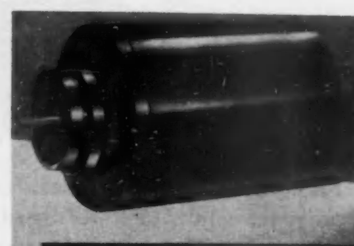
4 percent from 10 cps to 1,000 kc at minus 10 to plus 55 deg C
Stability: within 1 percent for line voltages between 105 and 125 volts
Weight: approximately 5 lb
—Daven Co., Livingston, N. J.

Circle No. 213 on reply card

PLUS. . . .
(214) The "Minispace", a small precise **analog computer** for engineers and physicists, was recently unveiled by **Solartron, Inc.**, North Hollywood, Calif. . . . (215) The ED-500 eddy **current test instrument**, developed by **Magniflux Corp.**, Chicago, Ill., provides a simple solution to crack detection and sorting problems. . . . (216) A new **synchro test set**, manufactured by **Theta Instrument Corp.**, East Paterson, N. J., will measure electrical error, fundamental null, total null, transformation ratio, and phase shift of any synchro, resolver, or gimbal component. . . . (217) **American Instrument Co.**, Silver Springs, Md., offers a new double-unit **thermometer calibrating bath** that enables an operator to calibrate a large number of thermometers at two different temperatures at the same time.

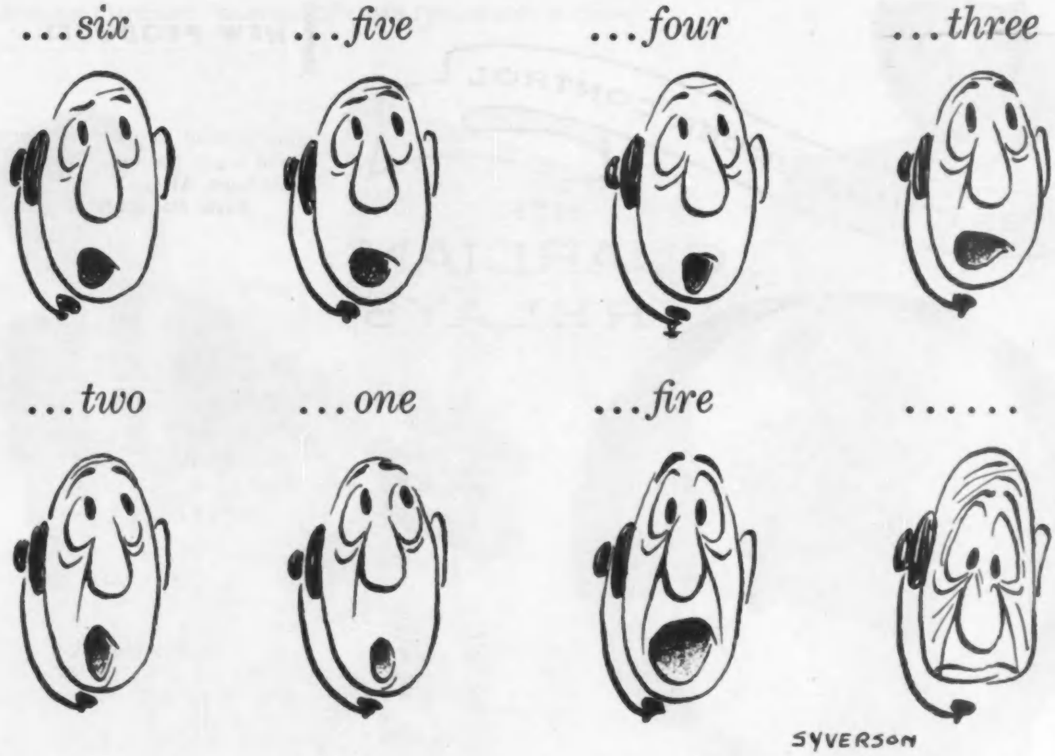
Circle 214, 215, 216 or 217 on reply card

PRIMARY ELEMENTS & TRANSDUCER



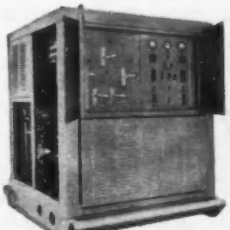
BUILT-IN ALIGNMENT

A built-in alignment cell in this new 13-digit shaft-angle encoder establishes accurate optical-mechanical concentricity and tests operational performance. According to the manufacturer, accuracy of shaft-angle indication can be realistically held to within 2.5 min of arc. At 366 rpm, probability of a one-bit error is 0.75. Readout is possible up to a maxi-

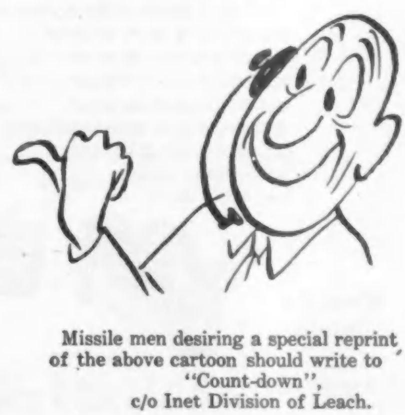


When the target is space and a million dollars' worth of missile rests idly on the ground—not even a long countdown helps. In a showdown situation, the successful shoot depends on the "go, no-go" type of test that pinpoints the trouble.

NEXT TIME...LOOK TO INET FOR PRECISE GROUND POWER



This INET 400-cycle ground power unit was tailor-made for the Atlas. In meeting all of Convair's specifications for pre-flight calibration of electrical systems, the unit operates in parallel with the missile's power system and provides remote control regulation. Frequency regulation is ±0.2%. With shock load equal to a third of rated output, frequency recovers to ±0.2% in 0.15 seconds. Voltage regulation is ±0.5% with recovery time at 0.30 seconds.



Missile men desiring a special reprint of the above cartoon should write to "Count-down", c/o Inet Division of Leach.

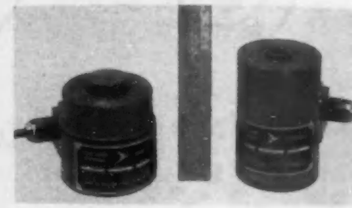
INET DIVISION **LEACH** CORPORATION

18435 SUSANA ROAD, COMPTON, CALIFORNIA

DISTRICT OFFICES AND REPRESENTATIVES IN PRINCIPAL CITIES OF U. S. AND CANADA

mum reading rate of 100 complete digital words per sec.—Dychro Corp., Watertown, Mass.

Circle No. 218 on reply card



LOAD CELLS

A complete line of hermetically sealed load cells features individual dead-weight calibration and extremely high output.

Characteristics:

Capacities: 500 to 200,000 lb compression types and 500 to 50,000 lb tension types
Overload capacity: 225 percent
Accuracy: within 0.2 percent
—Revere Corp. of America, Wallingford, Conn.

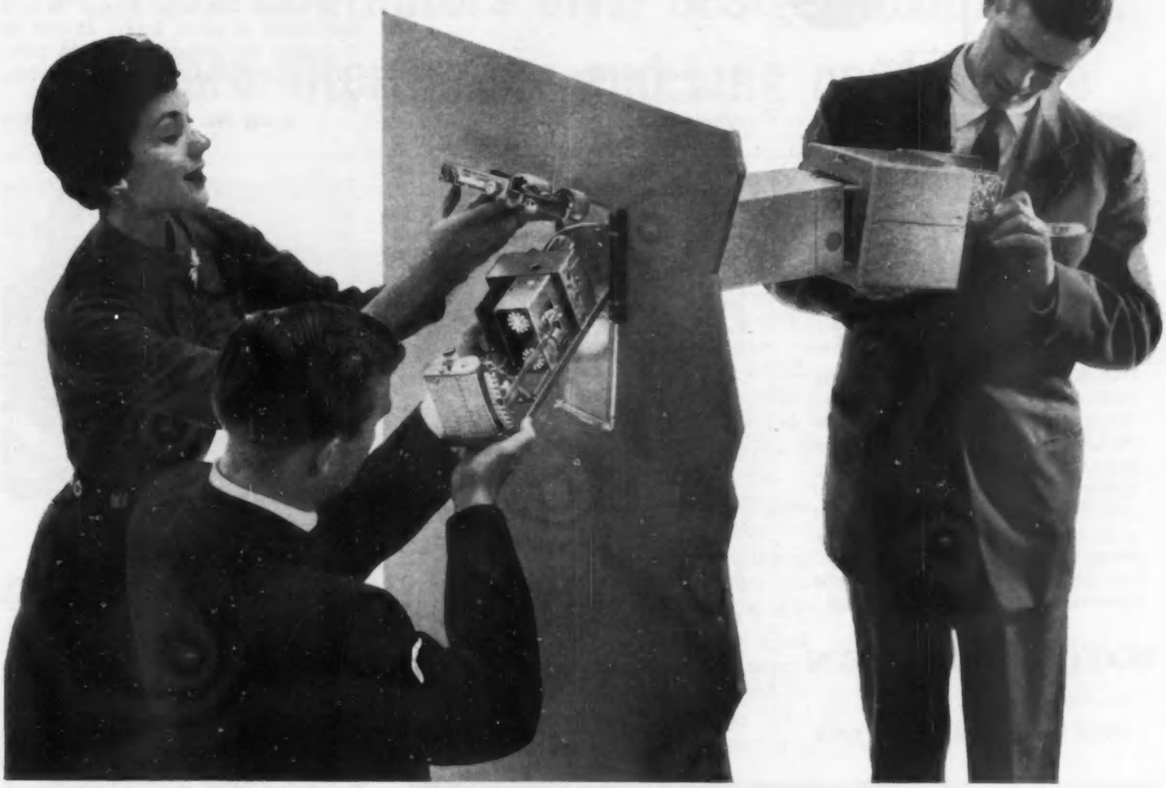
Circle No. 219 on reply card

CHARGE-LEVEL CONTROL

The Indicon I-100 level control uses gamma radiation and Geiger counter pickups to maintain charge level in foundry furnaces. Since all components are outside the furnace, the instrument is safe from corrosion and mechanical damage. The radioactive source, cobalt 60, is mounted in a windowed lead safe between minimum and maximum levels, and a Geiger counter is mounted at each of these levels opposite the source. When both receive strong signals, the charge is too low. If both receive weak signals, charge is too high. Unit requires only 150 watts at 115 volts, 60 cycles.—Whiting Corp., Harvey, Ill.

Circle No. 220 on reply card

PLUS. . . .
(221) A. H. Emery Co., New Canaan, Conn., has released data on a new line of **load cells** for industrial applications in the 0-to-1,000-lb range. . . . (222) The Model 36628 **rate gyro,** produced by **G. M. Giannini & Co., Inc.,** Pasadena, Calif., uses an ac inductive pickoff to provide high out-



SECOND MAJOR BREAKTHROUGH IN SEVEN YEARS
THE UNITIZED AUTRONIC CONTROLLER

Swartwout revolutionized process control when it first introduced the AutroniC Control System in 1951. All limitations of the past were immediately swept away.

Impossible performance specifications became a reality. Zero hysteresis, infinite sensitivity and no signal lag became tangible qualifications that *only* this new instrumentation concept could fulfill.

Again in 1957, Swartwout amazed industry by producing the Unitized AutroniC design. Years ahead in its field . . . no control instrument has ever been as completely unitized.

No controller has ever been as *practically* unitized in terms of flexibility and the simplest, easiest maintenance ever.

Every component section plugs in. They're all interchangeable. A simple indicator becomes a sophisticated recorder-controller in minutes and without tools.

In performance . . . maintenance . . . flexibility, you're years ahead with AutroniC Instrumentation. And, you'll stay ahead because of Swartwout continuing leadership in the control field.

***4 new bulletins* describe the Unitized AutroniC System. Request Bulletin Series A-801.**

SWARTWOUT

. . . world leader in electronic process instrumentation

THE SWARTWOUT COMPANY
18511 EUCLID AVENUE,
CLEVELAND 12, OHIO

S.A. 1600

put with excellent linearity and null stability. . . . (223) **Ultradyne, Inc.**, Albuquerque, N. M., is marketing a new improved dual-coil, variable reluctance **pressure transducer** for use with commercially available carrier systems and bridge circuits. . . . (224) A probe that permits direct reading of dielectric constant and dissipation factor in most nonconductive liquids is now available from **Delsen Corp.**, Glendale, Calif.

Circle No. 221, 222, 223, or 224 on reply card

CONTROLLERS, SWITCHES & RELAYS

PROVIDES 3PDT SWITCHING

A new lightweight, subminiature, armature-type relay for commercial and industrial applications occupies about 0.5 cu in., weighs ⅛ oz, and operates on as little as 750 milliwatts. Designated the KM, this dc relay provides switching arrangements up to 3pdt, can handle up to 2 amp at 115 vac, and is capable of a million operations at rated load. It can be furnished for voltages up to 48 volts. —Potter & Brumfield, Inc., Princeton, Ind.

Circle No. 225 on reply card

UPS SAMPLING RATE

The Type 33-514 high-speed commutator shown here triples the sampling rate of the MilliSADIC data-processing system: it provides for sequentially sampling up to 100 inputs at a rate of 1,200 samples per sec. Essentially an automatic, high-speed, 100-throw, single-pole switch, the unit contains two groups of 10 low-speed 5pst relays driven by two "ring" counters. Two groups of five spst high-speed relays driven alternately by two separate "ring-of-five" counters are sampled as they operate by two alternately closing high-speed transistor switches. At rates below 400 samples per sec, the transistor switch position of the commutator is by-passed.—Consolidated Electrodynamics Corp., Pasadena, Calif.

Circle No. 226 on reply card

EXPLOSION-PROOF

A new, sensitive remote-bulb temperature control. Type D98-A, for use in explosive vapors and gases, consists of a liquid-filled thermal system and bellows plus two individually adjustable snap-action switches. The latter are available in a variety of types. All are rated for 15 amps at 115 or 230 vac.—United Electric Controls Co., Watertown, Mass.

Circle No. 227 on reply card

INTERVAL TIMER

A new type of programming timer offers precise control of up to 16 sequential-time intervals. Each may be independently set in 10-sec increments

NEW PRODUCTS

between 0 and 30 min. At the end of each interval a chime sounds for manual operations and an electrical contact momentarily closes to operate switches, solenoids, etc. Control signals may be either 6 vdc or 110-120 vac. Other models offer maximum intervals of 37.5 and 15 min.–Bald Eagle Corp., St. Paul, Minn.

Circle No. 228 on reply card

PRESSURE SWITCH

This rugged, temperature-stable pressure switch will open or close contact at any preset pressure in the range of 0.2 to 15.0 psia. It weighs only 3.5 oz and operates through a temperature range from minus 65 to 225 deg F. Repeatability is within 0.1 psia. Base of the switch measures 2 in. sq. –Aero Mechanism, Inc., Culver City, Calif.

Circle No. 229 on reply card

CONVEYOR CONTROL

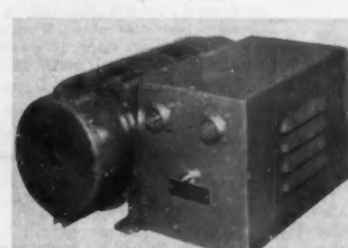
A new, multiple-drive conveyor control designed to provide for load sharing combines a Varidyne power unit with a Dial-A-Torq control unit for simultaneously modifying the slip of all motors in the conveyor system. The unit does not affect the starting characteristics of the motors; therefore, high breakaway torque is always available for difficult starting conditions.–U. S. Electrical Motors, Inc., Los Angeles, Calif.

Circle No. 230 on reply card

PLUS. . . .
(231) A new all-purpose **two-stage regulator,** combining the best features of both magnetic and electronic amplifiers, has been developed by **Clark Controller Co.,** Cleveland, Ohio. . . . (232) The Model BS-5003 **frequency sensing relay,** offered by **G-V Controls, Inc.,** East Orange, N. J., consists of a high-pass filter feeding a thermal sensing relay and is used to protect electronic equipment against damage due to low supply frequency. . . . (233) **Kurman Electric Co.,** Brooklyn, N. Y., is featuring a miniature version of a **power relay** with 10-amp contact arrangements up to 3pdt.

Circle No. 231, 232 or 233 on reply card

POWER SUPPLIES

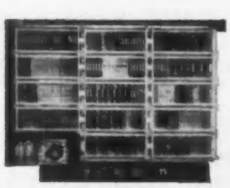


400-CYCLE INVERTER

This new industrial-type inverter, 28 vdc to 400 cycles, provides reliable performance and a much longer life than standard 6,000 rpm aircraft

Now—at the test site—completely automatic test control and data reduction can be handled by a single system incorporating the Ramo-Wooldridge RW-300 Digital Control Computer. The new RW-300 can schedule and closely control test routines, and it can collect, analyze, and record test data.

The versatile RW-300 utilizes input data as feedback to modify control actions, thus substantially shortening many test routines. In addition, the RW-300 directly logs both instrument data and complex relationships among these data. Thus, test results are available immediately. The time-consuming task of processing raw data through a separate computer, often remote from the test facility, usually can be eliminated.



For technical information on automatic test control and data reduction with the RW-300 and with special digital systems which utilize solid-state components exclusively, write: Director of Marketing, The Thompson-Ramo-Wooldridge Products Company, P.O. Box 45607, Airport Station, Los Angeles 45, California, or call OSborne 5-4601.

THE THOMPSON-RAMO-WOOLDRIDGE PRODUCTS COMPANY

CIRCLE 86 ON READER-SERVICE CARD

NEW PRODUCTS

types. Designed originally for ground support of guided missiles in transport, the device works on a battery input of 20 to 30 vdc or any standard 28 vdc source, yields an output of 687 va, single phase, 115 volts, 400 cps. An integrally-mounted regulator limits frequency and voltage changes to within $1\frac{1}{2}$ percent of their rated values.–The Louis Allis Co., Milwaukee, Wis.

Circle No. 234 on reply card

HIGH EFFICIENCY

Two new electromechanical, automatic voltage regulators use transistorized control circuits to detect changes in the output voltage and supply correction voltage to a motor-driven power circuit. Type EMT-4102 is a cabinet model; Type EMT-4102-R, a rack model.

Characteristics:

Input 95 to 135 volts, 50/60 cycles
Output: adjustable from 110 to 120 volts.
Load range: 0 to 17.5 amp
Efficiency: over 98 percent
Sensitivity: adjustable to within 1 percent
–The Superior Electric Co., Bristol, Conn.

Circle No. 235 on reply card

INSTANTLY REVERSIBLE

This 80-oz-in. continuous-duty synchronous motor provides instantaneous reversing through a spdt switch. Designed for heavy-duty operation, it maintains timing accuracy in either direction of rotation.

Characteristics:

Output speeds: $\frac{2}{3}$ to 3,600 rpm
Temperature rise: 40 deg C
Power required: 115 volts, 60 cycles
Dimensions: $2\frac{1}{2}$ in. diam, $1\frac{3}{4}$ in. long.
Weight: 14 oz
–Hurst Tool & Mfg. Co., Princeton, Ind.

Circle No. 236 on reply card

ALL-WEATHER MOTORS

A complete line of "climatized" vertical shaft motors in ratings to 2,000 hp, designed for indoor and unprotected outdoor service, suit a wide variety of industrial pumping applications. Insulating materials provide optimum resistance to moisture and chemical contaminants. Relatively

NEW ASCOP ELECTRONIC COMMUTATORS

Provide Greater Accuracy In Analog Sampling Systems

HIGH ACCURACY: 1% or better input-to-output accuracy for any mixed source impedances up to 25 K ohms, including linearity and offset.

NEGLIGIBLE BACK CURRENT: Maximum 1 microampere back current during channel "off" time.

These and other advantages make solid-state ASCOP Electroplexers® ideal for your data handling systems.

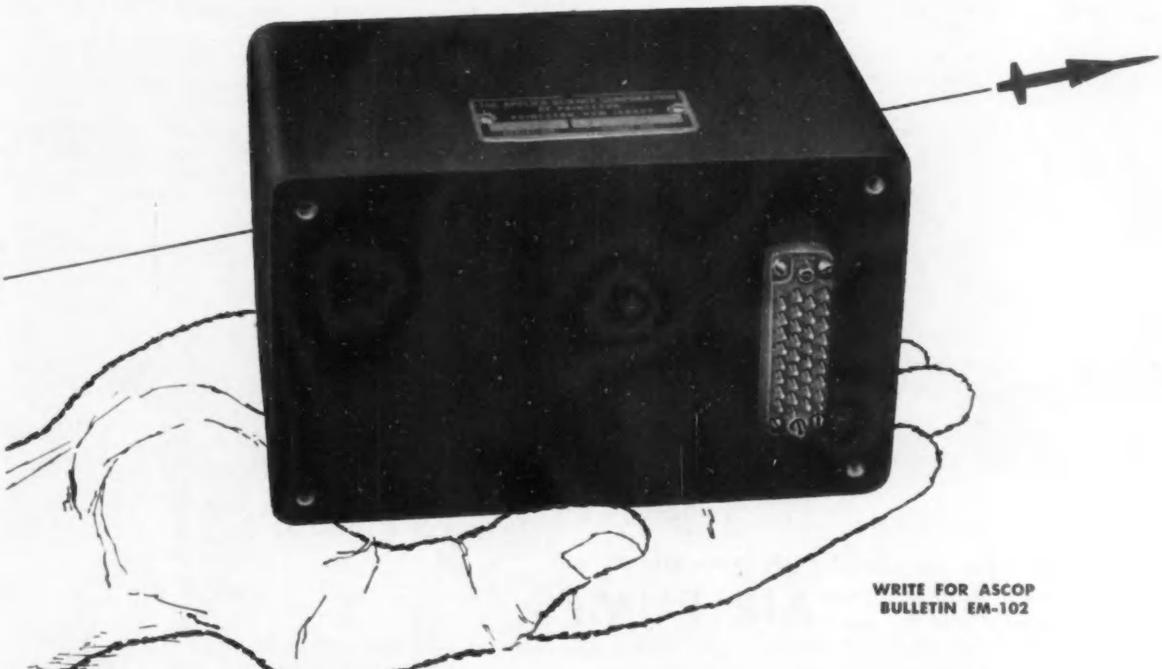
ENVIRONMENTAL EXCELLENCE: Meets MIL-E-5272A specification. Operates from −60°C to +85°C with special packaging available for extreme intermittent temperatures.

STANDARD OPERATION: Time-division multiplexing for 0-5V inputs in all IRIG standard PAM and PDM sampling rates.

INCREASED RELIABILITY: No moving parts. 5,000 hours of maintenance-free life.

LOW POWER CONSUMPTION: Less than 3 watts.

SMALL AND LIGHT: Size, 45 cubic inches; weight 2 pounds (typical).



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® APPLIED FOR

APPLIED SCIENCE CORPORATION OF PRINCETON

ELECTRO-MECHANICAL DIVISION

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CIRCLE 89 ON READER-SERVICE CARD

NEW PRODUCTS

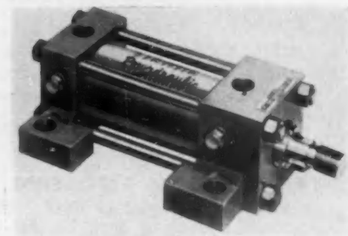
little cooling air is required and right-angle bends in the air flow system prohibit the entrance of snow and rain. Optional features include a nonreverse ratchet, part-winding or increment start connections, temperature detectors, space heaters, and snow covers.—The Louis Allis Co., Milwaukee, Wis.

Circle No. 237 on reply card

PLUS. . . .
(238) Synchronous motor driven **frequency changers** with 400-cycle, three-phase outputs are available in sizes as large as 250 kw from **Kato Engineering Co.**, Mankato, Minn. . . . (239) **Manson Laboratories, Inc.**, Stamford, Conn., has developed a medium-power general purpose **magnetic power supply** that features a peak-to-peak ripple of only 0.5 percent. . . . (240) For airborne applications, **Neff Instrument Corp.**, Pasadena, Calif., offers two completely transistorized **strain gage power supplies** for 1 or 3 amp at 5, 10, or 15 volts. . . . (241) **The Systron Corp.**, Concord, Calif., has announced a new precision **rms-to-dc converter** for industrial or laboratory measurements of ac voltages. . . . (242) Developed as an auxiliary power unit for missile control, a new type of **hydraulic power pack** is being produced by **Eastern Industries, Inc.**, Hamden, Conn.

Circle No. 238, 239, 240, 241 or 242 on reply card

ACTUATORS & FINAL CONTROL ELEMENTS



WELL SEALED

Called the Powrdraulic Series, a new line of high-pressure hydraulic cylinders are rated at 2,000 and 3,000 psi nonshock hydraulic, with a high safety factor. They are available in 13 mounting styles. Fully confined between tube and head on the outside diameter of the tube, the seal tightens when expansion of the tube by hydraulic pressure squeezes the O ring.—Hanna Engineering Works, Chicago, Ill.

Circle No. 243 on reply card

EASY TO MAINTAIN

Pictured is one of a new line of wafer-type butterfly valves. Outstanding features include: rugged actuator mounting, easy adjustment, accessi-

STRAIGHT TALK TO ENGINEERS

from Donald W. Douglas, Jr.

President, Douglas Aircraft Company

You may wonder what the future holds for the engineer who decides to build his career in the aircraft/missile industry.

In terms of permanent demand, this industry probably requires a greater proportion of engineers to total personnel than any other. Here at Douglas we are now employing more engineers than we did during World War II.

In regard to professional standing, the aircraft/missile industry deals always with the latest state of the art in every engineering and scientific specialty involved. Its engineers are in one of the best informed and highest prestige fields in their profession.

Whatever your present activity, if you decide to move into aircraft, missile and space technology, we would like to talk with you.

Please write to Mr. C. C. LaVene,
Douglas Aircraft Company, Box D-620,
Santa Monica, California

bility, and maximum actuator power delivery. The special mounting plate provides maximum support and is slotted for precise positioning of the actuator. Bearing brackets permit easy access to the packing box and removal of the self-centering gland follower and gland, without disconnecting linkage or removing brackets. Units are available in sizes from 2 to 24 in., with power, hand-wheel, or lever actuation.—Mason-Neilan, Norwood, Mass.

Circle No. 244 on reply card

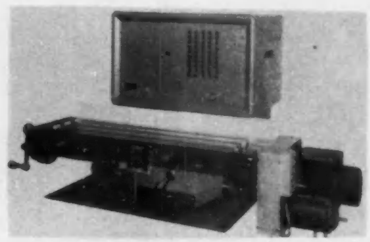


TABLE POSITIONER

Building block design on a new line of numerically-controlled positioning systems makes these systems easily adaptable to most machine tools, both old and new. All positional distances in translation are measured and set in inches, on an absolute basis. Models are available in pushbutton keyboard types for manual setup and fully automatic versions controlled by standard 1-in. punched paper tape. Units cover ranges to 99.999 in. in steps of 0.001 in. Both accuracy and repeatability are within 0.00025 in.—Wang Laboratories, Inc., Cambridge, Mass.

Circle No. 245 on reply card

PLUS . . .

(246) A complete line of **miniaturized air cylinders**, valves, and fittings, recently introduced by **Air-Mite Devices, Inc.**, Chicago, Ill., combines rugged construction with compact design. . . . (247) **Allied Control Co., Inc.**, New York, has announced a new line of miniature, stainless steel, **solenoid valves**, available in two- and three-way, normally-open or normally-closed designs with pressure ranges to 400 psi.

Circle No. 246 or 247 on reply card

COMPONENT PARTS

CARRIER AMPLIFIERS

Models CA3 and CA5 strain gage carrier amplifiers operate from a typical airborne 28-vdc supply and provide an output of 0 to 5 vdc, exactly proportional to the pressure, acceleration, or load being measured. Units may be used with any strain gage transducer. In operation, the amplifier converts the 28-vdc supply to a pulsating 10-kc square wave, which is modulated by the transducer and amplified to the 0-5-volt range. A demodulator unit provides the dc output.—Statham Instruments, Inc., Los Angeles, Calif.

Circle No. 248 on reply card

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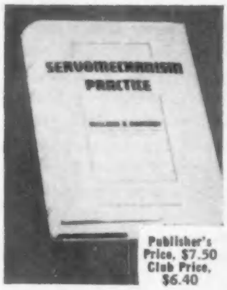
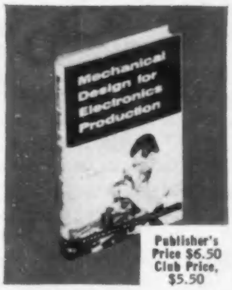


Servomechanism Practice by W. H. Ahrendt. How to solve problems of servo design, manufacture, test, and adjustment.



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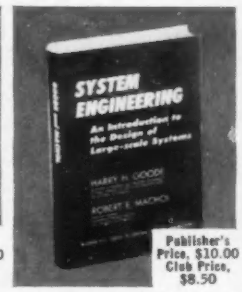

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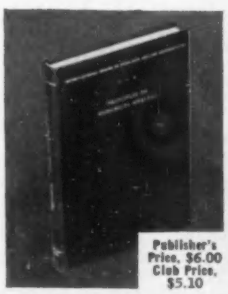
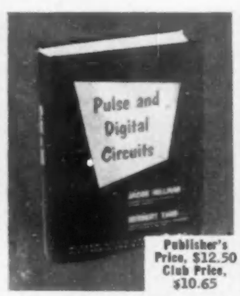
Instruments for Measurement and Control by W. G. Holzbock. Gives you latest advances in process instrumentation.

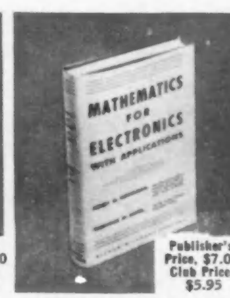


Principles of Numerical Analysis by A. S. Householder. Mathematics for setting up and evaluating computing routines.

Handbook of Industrial Electronic Control Circuits by J. Markus and V. Zeluff. Over 300 tested control circuits.



Pulse and Digital Circuits by J. Millman and H. Taub. Explains circuits for effective electronic system design.



Mathematics for Electronics with Applications by H. M. Nodelman and F. W. Smith, Jr. For solution of practical problems.

Modern Physics for the Engineer by L. N. Ridenour. Examines physical science on which modern engineering is based.

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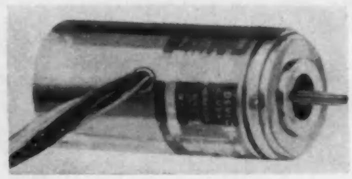


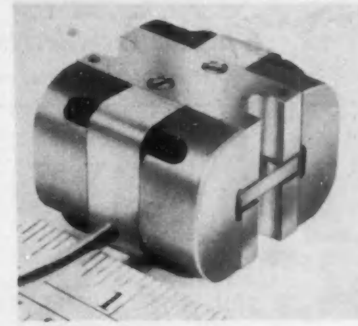
HIGH PERFORMANCE

This size 10 damping-type motor tachometer is said to provide generator performance equivalent to that obtained in a size 11 frame. Variations available include gearheads, clutch, temperature compensation circuits, and normal changes in the output shaft.

Characteristics:

Minimum stall torque: 0.5 oz-in.
Output gradient: 0.5 volt per 1,000 rpm
Temperature range: minus 54 to plus 105 deg C
Main, reference windings: 30 volts
Control winding: 30 volts, center-tapped
—Eastern Air Devices, Inc., Dover, N. H.

Circle No. 249 on reply card



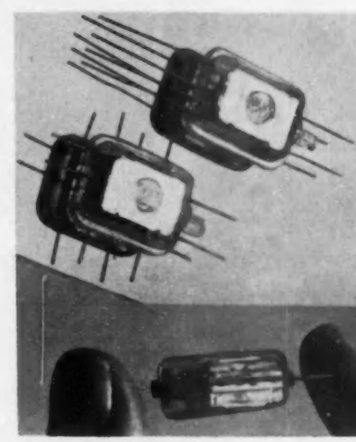
TORQUE MOTOR

One of a family of five, the Model 102 torque motor is a miniature, high-performance unit of extremely rugged construction. It exhibits practically no saturation over the normally used regions of current, displacement, and force, and is very efficient in terms of its performance-to-weight ratio.

Characteristics:

Output force: ± 5 lb, midposition
Output stroke: ± 0.007 in.
Hysteresis: 2 percent maximum
Resonant frequency: 800 cps
—American Measurement & Control Inc., Waltham, Mass.

Circle No. 250 on reply card



NEW TUBE ENVELOPE

Applicable to a complete line of receiving tubes, a new tube envelope design offers reliability and high dimensional accuracy in a conventional electrode structure. Features include wider spacing between input and output leads, thus minimum pickup or feedback. Diameters of the lead wires range from 0.020 to 0.028 in. All lead welds to the mount structure are in a single plane for accessibility and ease of control.—Westinghouse Electric Corp., Pittsburgh, Pa.

Circle No. 251 on reply card

GET

more information about

1. Advertised products
2. New product items
3. Catalogs and bulletins

All advertisements, new products and literature items are numbered for your convenience.

One of these handy prepaid post cards will bring you detailed information

HOW TO USE THESE CARDS:

1. Find the key number on item of interest
2. Circle this number on one of the cards
3. Mail card immediately

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Reader Service Department 1

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330 West 42nd Street
New York 36, N. Y.

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CONTROL ENGINEERING
330 West 42nd Street
New York 36, N. Y.

INSTRUCTIONS

Use these reader service cards to get more information on advertised products, new product items or catalogs and bulletins appearing in Control Engineering

IMPORTANT: Circle key numbers below and mail before January 1, 1959

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
1	11	21	31	41	51	61	71	81	91	101	111	121	131	141	151	161	171	181	191
2	12	22	32	42	52	62	72	82	92	102	112	122	132	142	152	162	172	182	192
3	13	23	33	43	53	63	73	83	93	103	113	123	133	143	153	163	173	183	193
4	14	24	34	44	54	64	74	84	94	104	114	124	134	144	154	164	174	184	194
5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195
6	16	26	36	46	56	66	76	86	96	106	116	126	136	146	156	166	176	186	196
7	17	27	37	47	57	67	77	87	97	107	117	127	137	147	157	167	177	187	197
8	18	28	38	48	58	68	78	88	98	108	118	128	138	148	158	168	178	188	198
9	19	29	39	49	59	69	79	89	99	109	119	129	139	149	159	169	179	189	199

200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390
201	211	221	231	241	251	261	271	281	291	301	311	321	331	341	351	361	371	381	391
202	212	222	232	242	252	262	272	282	292	302	312	322	332	342	352	362	372	382	392
203	213	223	233	243	253	263	273	283	293	303	313	323	333	343	353	363	373	383	393
204	214	224	234	244	254	264	274	284	294	304	314	324	334	344	354	364	374	384	394
205	215	225	235	245	255	265	275	285	295	305	315	325	335	345	355	365	375	385	395
206	216	226	236	246	256	266	276	286	296	306	316	326	336	346	356	366	376	386	396
207	217	227	237	247	257	267	277	287	297	307	317	327	337	347	357	367	377	387	397
208	218	228	238	248	258	268	278	288	298	308	318	328	338	348	358	368	378	388	398
209	219	229	239	249	259	269	279	289	299	309	319	329	339	349	359	369	379	389	399

Name ____________________ Title ____________________

Company ____________________

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2	12	22	32	42	52	62	72	82	92	102	112	122	132	142	152	162	172	182	192
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4	14	24	34	44	54	64	74	84	94	104	114	124	134	144	154	164	174	184	194
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9	19	29	39	49	59	69	79	89	99	109	119	129	139	149	159	169	179	189	199

200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360	370	380	390
201	211	221	231	241	251	261	271	281	291	301	311	321	331	341	351	361	371	381	391
202	212	222	232	242	252	262	272	282	292	302	312	322	332	342	352	362	372	382	392
203	213	223	233	243	253	263	273	283	293	303	313	323	333	343	353	363	373	383	393
204	214	224	234	244	254	264	274	284	294	304	314	324	334	344	354	364	374	384	394
205	215	225	235	245	255	265	275	285	295	305	315	325	335	345	355	365	375	385	395
206	216	226	236	246	256	266	276	286	296	306	316	326	336	346	356	366	376	386	396
207	217	227	237	247	257	267	277	287	297	307	317	327	337	347	357	367	377	387	397
208	218	228	238	248	258	268	278	288	298	308	318	328	338	348	358	368	378	388	398
209	219	229	239	249	259	269	279	289	299	309	319	329	339	349	359	369	379	389	399

Name ____________________ Title ____________________

Company ____________________

Address ____________________ City __________ Zone ______ State ______

1.

Circle number on card that coincides with key number listed at bottom or adjacent to item of interest.

2.

Fill in your name, title, company and address.

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Mail card immediately.

New! Miniaturized!

Kellogg Type "L" Relay

TYPE "L" RELAY FACTS							
	FORM A	FORM B	FORM C	FORM D			REMARKS
CONTACT FORMS	(MAKE)	(BREAK)	(BREAK-MAKE)	(MAKE BEFORE BREAK)			13 SPRINGS MAX. PER STACK. ONE FORM D MAX. PER STACK.
	TWIN CONTACTS			SINGLE CONTACTS			
CONTACT RATING (NON-INDUCTIVE)	PALLADIUM .062" x .020" 4 Amps. 150 Watts	GOLD .062" x .020" 1 Amp. 150 Watts	SILVER .062" x .020" 2 Amps. 100 Watts	PALLADIUM .093" x .031" 4 Amps. 450 Watts	TUNGSTEN .125" x .050" 3 Amps. 450 Watts	SILVER .125" x .050" 4 Amps. 450 Watts	RATINGS PERTAIN TO CURRENT CARRYING CAPACITY UNDER NORMAL CONDITIONS. SPECIAL APPLICATIONS USUALLY REQUIRE ENVIRONMENTAL TESTING.
	STANDARD COILS		SLUG COILS				
TIMING (IN MILLI-SECONDS)	OPERATE RANGE 3-30	RELEASE RANGE 4-20	OPERATE RANGE 20-60	RELEASE RANGE 30-100			TIMING VALUES ARE SUBJECT TO FURTHER LIMITATIONS DEPENDING UPPON CONTACT ARRANGEMENT AND APPLIED VOLTAGE
	COIL RESISTANCE		WEIGHT	RESIDUALS			
MISC.	SINGLE WOUND UP TO 20,000 OHMS	DOUBLE WOUND UP TO 6500 OHMS EACH WINDING	APPROX. 2¼ OZ.	AVAILABLE WITH SCREW OR FIXED TYPE RESIDUALS			

"Compact, lightweight, extremely versatile, *reliable*" . . . these are some of the comments of engineers who have tested Kellogg's new type "L" relay. It is a sturdy re-engineered version of the model used for years in telephone offices around the world. Now, its many new features make it particularly adaptable to industrial applications including computer systems, two-way radio and automation devices.

Efficient design gives the Kellogg type "L" more operating force than relays of comparable size. This means greater sensitivity, gram pressure and more springs per pileup. In addition, the new relay features:

- **rear mounting,** for ease of wiring
- **wide variety of coils** for any circuit requirements; single or double wound
- **bifurcated stationary springs** for independent contact action and high reliability; (single contacts also available)
- **heavy duty bronze** yoke and stainless steel bearing pin insure long life and stable adjustment
- **single or double** arm type armatures available
- **hermetically sealed** models, if desired
- **operating speed:** minimum of 1 to 2 milliseconds
- **contact points:** gold, silver, palladium, tungsten; other materials available
- **residual:** adjustable
- **time delay:** heel-end slugs and armature-end slugs for release time delay and operate time delay, respectively
- **terminals:** slotted
- **weight:** Net, 2¼ oz.
- **dimensions:** 2-1/4" L x 1-1/8" W, ranging in height from 17/32" to 1-1/16" (max.)
- **operating voltages:** up to 220 V.D.C.

Behind the superior reliability and design of Kellogg's type "L" relay are more than 60 years of experience as a leading producer of telephone equipment. And as the communications division of International Telephone and Telegraph Corporation, Kellogg has the research talent of 3500 engineers and technicians at its disposal.

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BULLETINS AND CATALOGS

(300) RECTIFIER CONTROLS. Fairfield Engineering Corp. Bulletin, 8 pages. Describes the operation and application of a new line of magnetic rectifier controls for driving General Electric's new silicon controlled rectifiers. Illustrations include schematics of several types of control systems and a circuit diagram showing the internal wiring of a general-purpose unit.

(301) "PACKAGED POWER". Kepco Laboratories, Inc. Catalog, 16 pp. Covers a complete line of transistorized, magnetic, and vacuum-tube voltage-regulated power supplies. Photos and specification tables accompany descriptive information.

(302) TINY MOTOR GENERATOR. Beckman Instruments, Inc. Data sheet 1402, 4 pp. Deals with a new 26-volt, 400-cycle, size 8 servomotor-rate generator, provides data on construction features, motor dynamics, generator output, and other characteristics of interest to the systems designer.

(303) PROGRAM READER. Taurus Corp. Bulletin, 4 pages. Introduces a punched-card sensor designed to save time in programming data already punched on standard IBM or Remington-Rand code cards. Operation is fully described and illustrated.

(304) TEMPERATURE DETECTORS. Leeds & Northrup Co. Catalog EN-S4, 36 pp. Offers complete information on this company's line of Thermohm resistance thermometers. Illustrates typical applications in ceramics, chemicals, food and drugs, glass, metalworking, refining, and other industries.

(305) DECADE COUNTERS. Burroughs Corp. Bulletin No. 826, 6 pp. Provides detailed descriptions of four decade counters containing beam-switching tubes and Nixie indicators. Drawings show typical associated circuits such as driver circuits, a 1-microsec reset circuit, a one-decade preset circuit, and a remote Nixie readout circuit.

(306) ACCURATE METERING. Milton Roy Co. Application Engineering Data Sheet A-58-1, 2 pp. Shows how one company uses a controlled-volume pump to continuously maintain chemical balance in a chlorine drying process. Includes a flow diagram of the installed system.

(307) LEVEL CONTROLLER. Robertshaw-Fulton Controls Co. Technical Bulletin RF-587, 4 pp. Gives details of a new pneumatic-electronic level control device for liquid and granular media. Last page covers specs and installation dimensions.

(308) BY-PASS ROTAMETERS. Schutte & Koerting Co. Bulletin 18B, 4 pp. A capacity table, two graphs, and a step-by-step procedure tell the reader how to select the proper-size by-pass rotameter for a particular application. Piping requirements for placing the primary element included.

(309) MOTOR CONTROLS. General Electric Co. Bulletin GEA-4979D, 12 pp. Provides information on GE's line of industrial motor control centers in NEMA sizes 1 through 6. Units of NEMA Class I and II construction are illustrated.

(310) PILOT PLANTS. Consolidated Electrodynamics Corp. Bulletin 3013, 4 pp. Briefly discusses the operations and application of the "micro-plant", a compact automatic pilot plant designed for process studies and small enough to fit in the average office.

(311) LEVEL TRANSMITTER. Fischer & Porter Co. Specification 13D1460, 2 pp. Covers performance, operational limits, range, construction, and design features of a new force-balance differential pressure transmitter, used primarily for level measurement.

(312) DIODE TESTER. Atlantis Engineering Corp. Brochure, 4 pages. Includes electrical and physical specifications on a new automatic diode tester capable of handling 3,600 components per hour.

(313) PHOTOELECTRIC CONTROLS. Electronics Corp. of America. New edition of Bulletin PA 561, 24 pp. Contains detailed specifications, complete descriptive data, operational charts, and a concise selector guide to photoelectric systems for industrial control applications.

(314) T'COUPLE ASSEMBLIES. Thermo Electric Co., Inc. Bulletin EDS-47, 12 pp. Describes a line of custom-built, multithermocouple assemblies for obtaining temperature readings at various levels in reactors, catalyst beds, furnaces, and other deep vessels.

(315) SELENIUM RECTIFIERS. Syntron Co. Bulletin, 4 pages. Lists, in chart form, continuous dc current ratings for a complete line of "vacuum process" selenium rectifier cells. Front cover illustrates dimensions for the various cell types.

(316) TIME DELAY RELAY. Tempo Instrument Co. Bulletin No. 0558, 2 pp. Includes specifications, application data, and performance curves for a new line of heavy-duty, transistorized, time delay relays. Sketches provide mounting dimensions and wiring information.

(317) THERMOCOUPLE TABLES. Pace Engineering Co. Booklet, 10 pages. Spiral-bound booklet contains thermocouple conversion tables for a 150 deg F reference temperature. Covers all the usual thermocouple materials and permits conversion from deg to mv or mv to deg.

(318) TORQUE MOTOR. Cadillac Gage Co. Engineering Bulletin 102, 1 page. Photo, specification list, dimension drawings, and a brief description tell the reader all he need know about this new lightweight torque motor.

(319) TEMPERATURE CONTROL. Francis Associates. Technical Abstract No. 3, 4 pp. Bulletin entitled "Temperature Control of Flowing Liquids" discusses a high-accuracy temperature-control system developed at MIT to verify feasibility of this type of control in inertial guidance components.

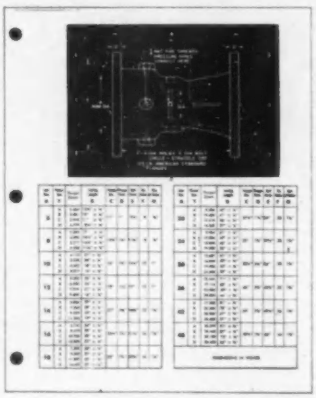
(320) WASTE TREATMENT DATA. Milton Roy Co. Application Engineering Data Sheet D-58-1, 4 pp. Using two schematic diagrams, the author explains the methods and equipment used for automatically metering chemicals in the continuous treatment of cyanide and chrome wastes.

APPLICATION LITERATURE

NOTE: To receive any of these items, write directly to the address given.

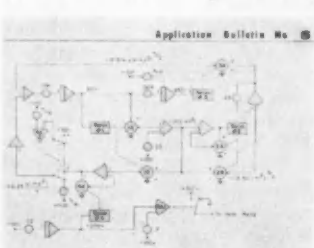
SENSING FLOW. B-I-F Industries, Inc., 345 Harris Ave., Providence, R. I. Technical Bulletin No. 100-P6, entitled "Standard Throats and Capacities for Dall Flow Tubes, Venturi Tubes, Venturi Nozzles", 12 pp.

Users of these particular types of differential producers must often be able to select proper throat size, calculate head loss, and determine whether a standard throat can be used for steam, gases, and liquids not covered by tabulated capacities. This bulletin provides simplified



formulas and tables for solving these problems. After the formulas are set up, illustrative examples are worked out to determine such economic factors as the annual pumping cost for a particular tube or nozzle under typical conditions. Tables and charts cover dimensional data, capacities, and performance. Page 7, shown above, is typical of the dimension tables; it covers Dall tubes for nominal pipe sizes from 6 to 48 in.

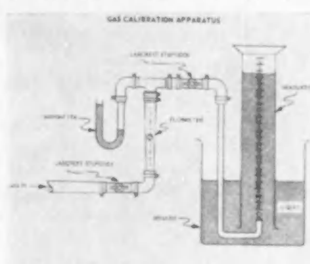
COMPUTER APPLICATION. Electronic Associates, Inc., Long Branch, N. J. Application Bulletin No. 5, a new six-pager, deals with one phase of the transistor production cycle. Entitled "An Analog Computer Study of the Stability of a Molten Zone Refining Process Used



in the Production of Transistors", the booklet describes the technique of simulating, on an analog computer, the characteristics of a germanium rod under various conditions of temperature, rod diameter, and length of molten zone. It points up the usefulness of the analog computer in solving nonlinear problems for conditions impossible to observe accurately in their true state. Circuit diagrams like the one shown here are used to illustrate the solution as it develops.

TESTING TECHNIQUES. Servo-Tek Products Co., 1086 Goffle Rd., Hawthorne, N. J. This 12-page engineering report, Serial No. 157, describes test procedures and equipment for determining stability, linearity, and eight other characteristics of dc tachometer generators. The authors treat each characteristic in a separate section. Subheads of each section include: Purpose of Test; Background; Test Equipment; Method of Test; and Test Results. In most cases the test results have been tabulated for the reader's convenience.

LOW-FLOW DATA. Fischer & Porter Co., 795 Jacksonville Rd., Hatboro, Pa. Catalog 10A9010, called the "Variable-Area Flowmeter Handbook", contains 15 pages of basic engineering data on the company's Tri-Flat low-flow rotameters. It shows how calibration data for these meters is established from a working equation



or by physical measurements and illustrates the latter with a sketch of the equipment setup (shown here). Illustrative material also includes density and viscosity tables, calibration charts, three two-page graphs of float characteristic curves, and a nomograph that simplifies selection of tube and float combination for any application. A short appendix lists common conversion formulas and shows a plot of pressure vs. density ratio for different operating temperatures.

MISSILE DATA SHEET. W. E. Schneider, La Salle Steel Co., P.O. Box 6800-A, Chicago, 80, Ill. This eight-page data sheet, up-to-date as of February 1958, lists all Army, Navy, and Air Force missiles by name and purpose. It also gives the names and addresses of both prime contractors and component subcontractors.

Types listed include: air-to-air, air-to-ground, ground-to-ground, ground-to-air, antisubmarine, antimissile, and intercontinental ballistic missiles.

ABSTRACTS

Cool Tubes Last Longer

From "Heat Dissipating Electron Tube Shields and Their Relation to Tube Life and Equipment Reliability" by Harvey Riggs, president of International Electronic Research Corp. Paper read to the United Kingdom Inter-Service Committee for the Coordination of Valve Development, Jan. 17, 1958.

Today tube failure and consequent equipment failure represent more of a problem than ever before. The reasons are simple. Equipment requirements have gone up while available space has diminished. Equipment has been miniaturized and subminiaturized. Tests have shown that in environmental temperatures near 100 deg C, some tubes are used that exceed their ratings in an ambient of only 25 deg C. Seldom do specifications or manufacturer's data sheets list pertinent tube-temperature data.

Just how important is this one factor, tube temperature? Studies reveal that:

1. Three equipment failures in every four are a direct result of tube failure.
2. The main cause of tube failure is high operating temperature.
3. Heat dissipating tube shields provide an immediate solution to a major part of the problem.

A mere 2-to-1 increase in tube life thus would eliminate one-third of all equipment failures. This would represent a greater improvement than if all other causes of failure were completely eliminated.

Perhaps the greatest single cause of high tube temperatures is the JAN-type electrostatic shield. Tests show that tubes equipped with this type shield may have bulb temperatures more than 100 deg C higher than bare tubes, and that most tubes exhibit hot spots opposite the center of the plate.

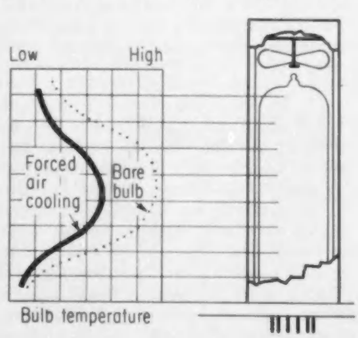


FIG. 1


FIG. 2

Attempts to cure the heat problem in shielded tubes with forced air convection have reduced the ambient environment but not the temperature gradient on the tube surface. Figure 1 illustrates this point.

Another and perhaps the best available method for cooling miniature shielded tubes is to use the heat-dissipating or Type B shield shown in Figure 2. This type shield has received very little attention, probably because too few designers realize the importance of adequate cooling.

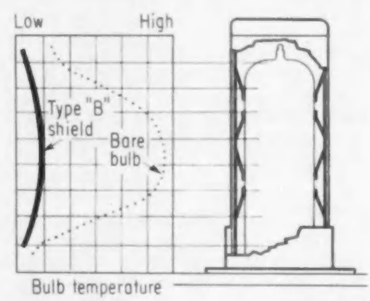


FIG. 3

The Type B shield dissipates heat by radiation, convection, and conduction. Not only does it reduce the general temperature of the envelope but it greatly reduces the temperature gradient on the tube surface. These effects are shown in Figure 3.

Another important consideration, of course, is the effectiveness of the shield in terms of electrostatic shielding and mechanical retention of the

tube. It has been established that here the spring-finger-lined, heat-dissipating shield is at least as effective as the solid-cover JAN shield.

Jet Diffuser Control

From "An Analog Study of a Shock-Position Diffuser Control on a Supersonic Turbojet Engine" by David Novik. A declassified NACA Research Report, NACA-RM-E56-E09a, prepared in August 1956 and declassified in May 1958. Available from the National Advisory Committee for Aeronautics, Washington, D. C.

In this study shock position was assumed to be controlled by air bleed through a diffuser-exit by-pass door operated by a second-order servomotor. Pressure disturbance resulting from changes in by-pass-door position had a negligible effect on controlled engine speed, whereas a disturbance in engine speed had a large effect on diffuser pressure and could impose severe requirements on diffuser control response. The controlled diffuser response improved with faster servomotor response and smaller diffuser dead-time and lag. The effect of diffuser dead-time on diffuser response exceeded that of diffuser lag.

Power Plants in 1975

From "Central Station Control—Today and Tomorrow" by W. A. Summers, Ebasco Services, Inc. Paper presented before the First Annual Power Conference, Power Div., ISA, New York, May 21-23, 1958.

The development and refinement of control systems for central power stations will depend largely on the economic future of the utility industry. Based on current predictions, this future looks very healthy:

Total installed thermal capacity:
 325 million kw in 1975 (90 milion kw in 1955)

Average and largest unit size:
 325 mw and 1,000 mw in 1975 (78 mw and 250 mw in 1955)

Plant investment per average unit in 1956 dollars (based on a coal-fired outdoor station):
 $46 million in 1975 (just under $13 million in 1955)

This growth may be evaluated in terms of 1) safety and cost of accidents, 2) investment cost, 3) fuel cost, and 4) labor. In the plant of

the future, safety will be just as important as it is today, and damage will be a far more costly proposition. A serious accident costing \$750,000 in 1956 would cost about \$2,500,000 in 1975. Relative first costs will also be up in 1975, unless new techniques and knowledge permit the use of safety factors based on evidence rather than guesswork. The importance of fuel costs cannot be minimized. On a medium-size unit a savings of only 0.25 percent could amount to a capitalized worth in 1975 of \$500,000. The slightest error can result in enormous dollar penalties.

Obviously, for the plant of the future, the utilization of labor must be given careful consideration. Human engineering studies have shown that while tomorrow's plants will require more and more skillful labor, the supply may not be able to meet the demand. This problem will be most pronounced in nuclear fuel plants. Thus plant automation appears inevitable. Future engineering efforts must aim at the reduction of investment per kw, reduction of replacement costs, and reduction of operating cost. Automatic controls must govern the entire power system, starting, stopping, loading, and switching all units. Heart of tomorrow's plant will be an area-dispatching computer, digesting such data as:

1. present electrical load, voltage and power factor
2. interchange commitments for kw and kvar
3. transmission line use
4. intersystem operating problems
5. time and data information
6. present and predicted weather at different parts of the system
7. plant operating performance

Short-term predictions will feed a sequential and logical control system which, in turn, will prepare equipment for operation and make necessary fuel change-overs. A data collection and monitoring system will scan, compare, and monitor data throughout the system and cycle. This will include operating, performance, and historical data. Statistical analysis equipment supplied with the historical and operating data will process accounting information and provide maintenance schedules and planning data. This data will also feed the computer.

This plant of tomorrow starts itself, runs itself, schedules its own removals from service, and executes these removals in an orderly manner. First of this type should be in service in the early 1960's.

NEW BOOKS

Britain's Electronics Industry

1958-9 Communications and Electronics Buyers Guide, Who's Who and Reference Book. *Edited by C. C. Gee, Editor of "British Communications and Electronics". 520 pp. Published by Heywood & Co., Drury Lane, London, England. $15.75.*

Based on four years' research into the British electronics industry, this book is actually more than just a buyer's tool. It represents the first objective and comprehensive survey of the industry itself. The term electronics has been widely interpreted to include communication and navigational aids, data processing and computing systems, measurement and control components, and nucleonic instrumentation as well as sound, reproduction equipment.

The main part of the guide is the Classification of Products. This includes 13,911 references under 2,700 generic headings covering materials, components and equipment.

A new feature, not normally found in previous attempts at industry surveys, is a Who's Who where some 1,800 prominent individuals in Britain's electronics field are indicated by their position and qualifications. The book also contains some 76 product surveys, giving comparative specifications of equipment such as computers, speed controls, displacement transducers, and microwave test gear.

A noteworthy attempt to define the industry statistically will aid all those who in the past have found it difficult to delineate the sections of this loosely organized industry. **Derek Barlow**

Written for Engineers

Introduction to Nonlinear Analysis. W. J. Cunningham, *Professor of Electrical Engineering, Yale University. 349 pp. Published by McGraw-Hill Book Co., Inc, New York, 1958. $9.50.*

The author should be congratulated for writing a textbook on nonlinear analysis specifically slanted towards the engineer rather than the mathematician. In his preface, Professor Cunningham notes that most of the material in this book was first presented in a graduate electrical engineering course at Yale University, where the emphasis was on ". . . the use of mathematical techniques as a tool for solving engineering problems. There was relatively little time devoted

to the niceties of the mathematics as such." These views are exemplified in the body of the book.

After a brief introductory chapter, the author devotes Chapter 2 to numerical methods of solving linear and nonlinear differential equations, including several checking procedures. It is regrettable that the author did not include a discussion of one of the most versatile of modern numerical techniques, the method of Boxer and Thaler. This method enables the analyst to obtain the time response of linear and nonlinear systems with a minimum of computational effort. At the very least, the method should have been included in the bibliography. Chapter 3 presents various graphical methods of solution: isoclines, phase plane, delta method, Lienard's method, Priesman's method, and graphical integration are explained with the aid of numerous examples.

Chapter 4 reviews standard analytical methods of solving linear and nonlinear differential equations. Here the author presents standard forms for the simpler, classical nonlinear equations and devotes some space to equations which are piecewise linear. The chapter closes with a brief treatment of equations leading to elliptic functions. The illuminating discussion of elliptic functions themselves is brief but enlightening. Chapter 5 contains a rather thorough analysis of singular points. The author's use of transformation matrices to obtain differential equations in normal (uncoupled) form is a striking demonstration of the power and compactness of matrix notation, and will prove interesting to the many electrical engineers accustomed only to impedance and admittance matrices.

Chapter 6 describes various analytical methods of solving nonlinear differential equations. Detailed discussions cover the perturbation method (Poincare's method of small parameters), variation of parameters, the Galerkin and Ritz averaging methods, and the principle of harmonic balance (method of Kryloff and Bogoliuboff). In Chapter 7 the principles developed in the preceding chapter are applied to the steady-state solution of nonlinear systems driven by oscillatory forcing functions. Harmonic and subharmonic generation are examined, as are jump phenomena and frequency entrainment of self-oscillators. This chapter also develops the concepts of the describing function and equivalent impedance.

In Chapter 8, the author presents

for the first time in any engineering text, methods for solving nonlinear differential-difference equations. Practical problems involving oscillators and delay lines are considered in great detail. Chapter 9 considers linear differential equations with varying coefficients. Here Professor Cunningham devotes considerable space to Floquet's theory for such equations, especially the Mathieu equation. The final chapter deals with the stability of nonlinear systems. The standard Nyquist and Routh-Hurwitz criteria are discussed, but more emphasis is placed on stability criteria for the Mathieu and Duffing equations.

The book contains 96 problems of varying difficuty, encompassing the classic equations of van der Pol and Rayleigh as well as positional servo systems and frequency-modulated oscillators. The annotated bibliography is brief but adequate.

Leslie R. Axelrod
Cook Research Laboratories

Text for Programmers

PROGRAMMING FOR AN AUTOMATIC DIGITAL CALCULATOR. *Kathleen H. V. Booth, Lecturer in Numerical Methods, University of London.* 238 *pp. Published by Academic Press, Inc., New York.* 1958. $7.50

Basically, this book is a text for beginners in digital computer programming. The author begins by briefly describing APEXC, an All-Purpose Electronic X-ray Calculator installed at Birkbeck College, London. The machine features simplicity rather than speed; its order code, containing only 15 orders, is probably one of the shortest in existence. This makes it an ideal machine on which to learn the basic ideas and techniques of programming.

The second chapter presents an overall picture of the programmer's function. Sections cover iteration, the schematic program, the detailed program, and the use of subroutines and subroutine libraries.

Programming for division and square root, and the preparation of miscellaneous subroutines, are covered in two chapters. Of particular interest here are the flow diagrams illustrating the "odd numbers" method for square-root extraction and the trial-and-error method of extracting an nth root.

Subsequent chapters cover techniques for programming miscellaneous, nonmathematical processes, as well as matrix operations, simultaneous linear equations, mechanical translation, interpretive processes, and, to a limited extent, automatic programming.

WHAT'S AHEAD: MEETINGS

OCTOBER

National Electronics Conference, sponsored by IRE, AIEE, Hotel Sherman, Chicago, Ill. Oct. 13-15

American Institute of Electrical Engineers, Tenth National Machine Tool Conference, Statler Hotel, Hartford, Conn. Oct. 13-15

Society of Industrial Packaging & Material Handling Engineers, Annual Exposiiton, Competition and Short Course, Chicago, Ill. Oct. 14-16

National Conference on Industrial Hydraulics, sponsored by Armour Research Foundation, Hotel Sherman, Chicago, Ill. Oct. 16-17

Institute of Radio Engineers, Professional Group on Communications Systems, Fourth National Aeronautical-Communications Symposium, Hotel Utica, Utica, N. Y. Oct. 20-21

Institute of Radio Engineers, 1958 East Coast Conference on Aeronautical and Navigational Electronics, Lord Baltimore Hotel, Baltimore, Md. Oct. 27-28

American Institute of Electrical Engineers, Fall General Meeting, Pittsburgh, Pa. Oct. 27-31

Computer Applications Symposium, sponsored by Armour Research Foundation, Morrison Hotel, Chicago, Ill. Oct. 29-30

Institute of Radio Engineers, 1958 Electron Devices Meeting, Shoreham Hotel, Washington, D. C. Oct. 30-31

NOVEMBER

International Conference on Astronautics, sponsored by Southwest Research Institute and Air Force School of Aviation Medicine, San Antonio, Texas Nov. 10-13

Institute of Radio Engineers, Northeast Electronics Research and Engineering Meeting, Mechanics Hall, Boston, Mass. Nov. 19-20

Electronic Computer Exhibition & Symposium, Olympia, London Nov. 28-Dec. 4

American Society of Mechanical Engineers, Annual Meeting, Statler Hotel, New York City Nov. 30-Dec. 5

DECEMBER

American Society of Mechanical Engineers, 23rd National Power Show, Coliseum, New York City Dec. 1-5

Eastern Joint Computer Conference, Theme: Modern Computers—Objectives, Design, and Application, Bellevue-Stratford Hotel, Philadelphia Dec. 3-5

WHAT'S AVAILABLE IN REPRINTS

The following reprints have been prepared to make important reference-type editorial material available to Control Engineering readers in convenient filable form. Some reprints are individual articles, while others are "packages"—several articles published over a period of time that logically supplement one another in the coverage of a specific phase of the control field. Any reprint can be obtained at the nominal cost listed below by filling in the order form and sending it, together with remittance, to Readers Service Dept. Quantity rates will be quoted on request.

How to Calculate a Control Earning Index, 12 pp. Shows a four-step method for predicting the increment of improved plant economy resulting from the addition of instruments and controls, and reports on experience in applying this method to three typical industrial processes. 30 cents.

Why Control System Bids Vary, December, 1957, 4 pp. A recurring demand forced the reprinting of this article. Dealing with the wide variance in bids that often occurs, with sophisticated control systems, the article explains why bids vary and offers guides to help in picking a supplier in competitive bidding. 15 cents.

Servo Design Techniques, 32 pp. A reprint of six related articles describing various electromechanical servo design techniques. Items include tacometer limiting, force-reflecting servos, calculating performance of drag-cup tachs, dual-mode servo compensation, applying packaged servo actuators, and cascading resolvers without amplifiers. 65 cents.

What's available in Flowmeters, 24 pp. A comprehensive coverage of positive displacement, velocity, and mass flowmeters, including characteristics, applications, and typical manufacturers; plus details of a special drag disc meter. 50 cents.

Selecting and Applying Control Timers, 24 pp. A compilation of four articles including a tabular description of timer functional parts, criteria for selecting and applying control timers, a tabular listing of available timer types and their characteristics, and techniques for custom-designing controlled for time-based routines. 50 cents.

What the Control Engineer Should Know About Reliability, April 1958, 8 pp. Not intended as a comprehensive treatise, but rather as a guide to aim the control engineer in the right direction, this staff-written article discusses the new concept of systems effectiveness, and briefly covers techniques for measuring reliability, predicting reliability, improving reliability, and costing reliability. Up to date reference sources are listed. 20 cents.

Survey of Numerically-Controlled Point-to-Point Positioning Systems, 72 pp. This complete series covers 31 domestic and foreign systems. Detailed operational and performance characteristics of each system are discussed. Individual parts of series are also available as listed below. $1.50.

Survey of Numerically-Controlled Point-to-Point Positioning Systems—III, March 1958, 16 pp. Includes detailed descriptions of nine machine tool control systems. 40 cents.

Survey of Numerically-Controlled Point-to-Point Positioning Systems—II, February 1958, 24 pp. Includes detailed descriptions of ten machine tool control systems. 50 cents.

Ready Reference Data Files, 24 pp. A must for every control engineer's library. Includes the first 12 data files published in Control Engineering—a diversity of topics, from system reliability through the cost of industrial temperature-measuring systems. Each one gives a method of solving a particular problem. 50 cents.

Servo Modulators—Their Application, Characteristics, and Availability, 36 pp. A group of four integrated articles covering all phases of electromechanical, electronic, solid-state, and magnetic modulators. Typical circuit diagrams, characteristics, and applications are given for each type, plus an 84-item bibliography and tables listing commercial units. 65 cents.

The Use of Digital Computers in Science, in Business, and in Control, 112 pp. A collection of 14 articles published over a period of two years as the Digital Application Series. Prominent authorities cover the application, programming, over-all system design, and commercial availability of digital computers in all phases of business, industry, and the military. $3.

Analysis Instrumentation — II — Refractometers, Infrared Analyzers, Photometric Analyzers, Colorimetry, 32 pp. This includes the second group of four articles of the Analysis Series. 60 cents.

Analysis Instrumentation — I — Nuclear Magnetic Resonance, Chromatography, Radioactivity, 32 pp. Reprint consists of first 4 articles of Analysis Instrumenta-

Reprint Order Form

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tion Series: a general introduction and detailed discussions of the three analysis techniques. Emphasis is on basic principles, practical tips, and the use of these techniques in automatic process control. 60 cents.

Basic Data on Process Control, 24 pp. A grouping of five articles on flow-process control, including: Basic Concepts of Feedback Control, Selecting Loops for Critical Control, Direct or Reverse Controller Actions, Modifying Valve Characteristics to Fit the Process, and Using Capacitance for Accurate Level Measurement. Practical information for every process control engineer. 50 cents.

How to Simulate Dead Time, 6 pp. Three tricky techniques for simulating dead time or transport lag. One's electronic, another is pneumatic-mechanical, and the third uses magnetic tape. A useful reference for control engineers concerned with process simulation. 15 cents.

Transistor and Thyratron Power Amplifiers, 28 pp. These three articles—one on transistors and two on thyratrons—were prompted by the increasing control application of transistors as low-power amplifiers and thyratrons as high-power amplifiers. In each case the emphasis is on practical application, circuit design, system stabilization, etc. 50 cents.

Static Switching Devices—New Tools for Industrial Control, May 1957, 28 pp. An independent consultant analyzes the complete field of industrial static-switching systems. Starting off with a review of basic switching logic, he covers circuit characteristics of the fundamental devices, commercially-available systems, actual applications, etc. 50 cents.

A Functional Analysis of Automatic Logging Systems, February 1956, 16 pp. An examination of the various techniques and equipment used in performing the eight functions in a generalized automatic logging system: transducing, scale-factor correction and linearizing, derivation of quantities, scanning, analog-to-digital conversion, programming and control, alarm, and recording or logging. 50 cents.

Automatic Machining—A View and a Preview, 24 pp. A quick look at some of the newer techniques that are being used to control machine tools. It deals primarily with recorded-information (numerical) control, discussing ways to automatically furnish machining instructions, ways to drive the tool, or workpiece, and ways to measure position and size. 50 cents.

A System Analysis Predicts Performance, June 1955, 16 pp. This rare case history shows how determining the dynamic characteristics of both the process and the control system (and considering both open to modification) can reduce cost and improve performance. 50 cents.

Digital Application Series. For those readers who would like to fill out incomplete sets of Application Series articles, the following are available as reprints:

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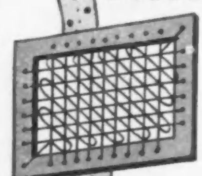

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